US Army Corps of Engineers
Waterways Experiment Station

FHWA

U.S. FISH & WILDLIFE SERVICE
DEPARTMENT OF THE INTERIOR

USDA NRCS
Natural Resources Conservation Service

NOAA

WETLANDS RESEARCH PROGRAM

TECHNICAL REPORT WRP-DE-17

A Regional Guidebook for Assessing the Functions of Low Gradient, Riverine Wetlands in Western Kentucky

by
William B. Ainslie, R. Daniel Smith,
Bruce A. Pruitt, Thomas H. Roberts
Earl J. Sparks, Larry West,
Gordon L. Godshalk, and Michael V. Miller

19990716 037

May 1999 — Operational Draft

Technical Report WRP-DE-17
May 1999

A Regional Guidebook for Assessing the Functions of Low Gradient, Riverine Wetlands in Western Kentucky

by William B. Ainslie

Wetlands Protection Section
U.S. Environmental Protection Agency
Region IV
61 Forsyth Street
Atlanta, GA 30303-3104

R. Daniel Smith

U.S. Army Corps of Engineers
Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Bruce A. Pruitt

Ecological Evaluation Section
U.S. Environmental Protection Agency
Region IV
960 College Station Road
Athens, GA 30605

Thomas H. Roberts

Tennessee Technological University
Department of Biology
P.O. Box 5063
Cookeville, TN 38505

Earl J. Sparks

U.S. Army Corps of Engineers
Louisville District
Newburgh Field Office
P.O. Box 489
Newburgh, IN 47629-0486

Larry West

University of Georgia
Department of Crop and Soil Sciences
Athens, GA 30602

Gordon L. Godshalk

Alfred University
Environmental Studies Program
Alfred, NY 14802

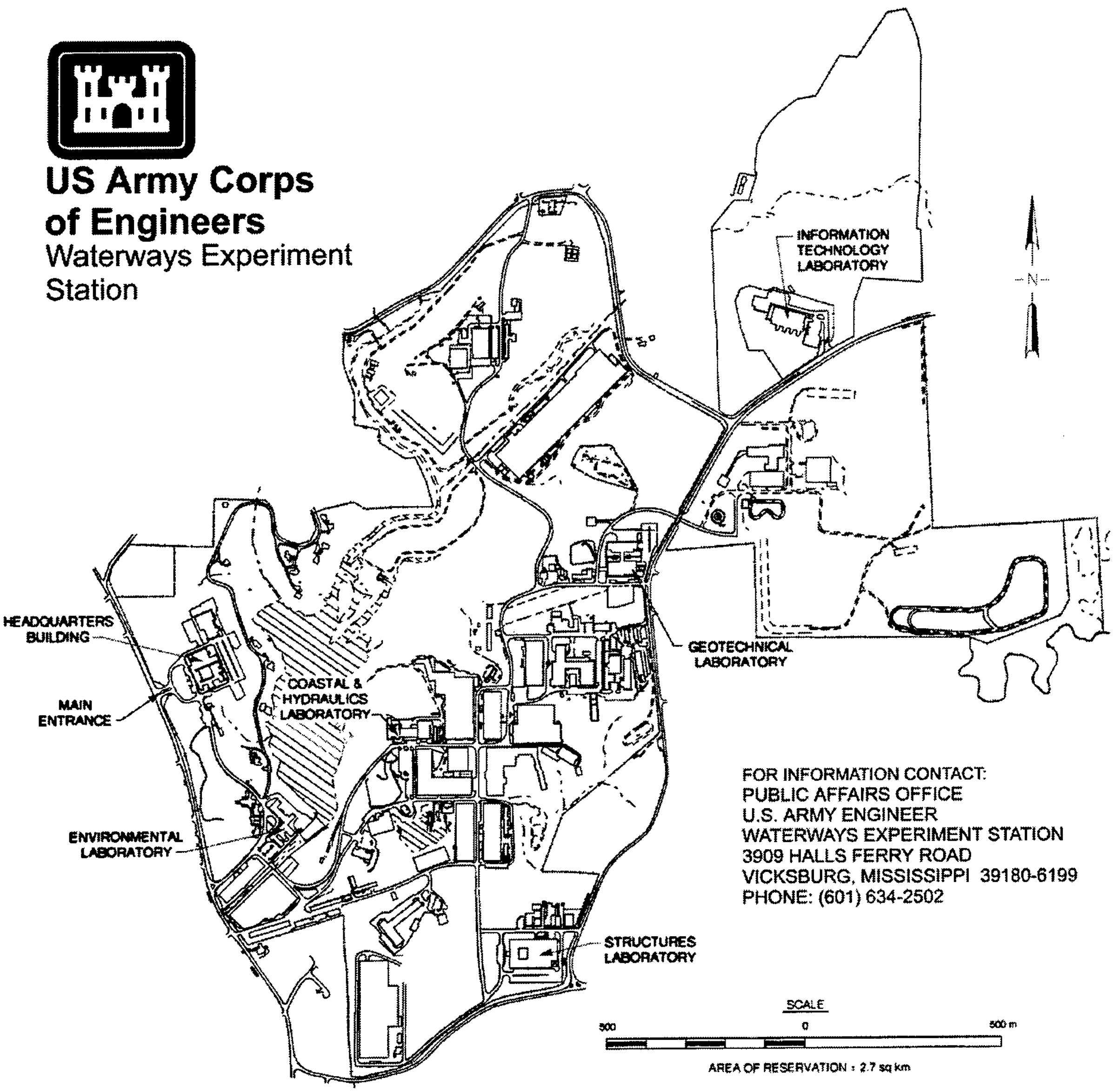
Michael V. Miller

Illinois State Geological Survey
615 East Peabody Drive
Champaign, IL 61820

Operational Draft

Prepared for U.S. Army Corps of Engineers
Washington, DC 20314-1000

US Army Corps of Engineers
Waterways Experiment Station



FOR INFORMATION CONTACT:
PUBLIC AFFAIRS OFFICE
U.S. ARMY ENGINEER
WATERWAYS EXPERIMENT STATION
3909 HALLS FERRY ROAD
VICKSBURG, MISSISSIPPI 39180-6199
PHONE: (601) 634-2502

Waterways Experiment Station Cataloging-in-Publication Data

A regional guidebook for assessing the functions of low gradient, riverine wetlands in western Kentucky / by William B. Ainslie ... [et al.] ; prepared for U.S. Army Corps of Engineers.
236 p. : ill. ; 28 cm. — (Technical report ; WRP-DE-17)
Includes bibliographical references.
Operational draft.
1. Wetlands — Kentucky — Guidebooks. 2. Wetland ecology — Kentucky —Guidebooks. 3. Wetland — Conservation — Kentucky — Guidebooks. I. Ainslie, William B. II. United States. Army. Corps of Engineers. III. U.S. Army Engineer Waterways Experiment Station. IV. Wetlands Research Program (U.S.) V. Series: Technical report (U.S. Army Engineer Waterways Experiment Station) ; WRP-DE-17.
TA7 W34 no.WRP-DE-17

Corps of Engineers Research Report Summary, May 1999

Assessing Wetland Functions

A Regional Guidebook for Assessing the Functions of Low Gradient, Riverine Wetlands in Western Kentucky

ISSUE: Section 404 of the Clean Water Act directs the U.S. Army Corps of Engineers to administer a regulatory program for permitting the discharge of dredged or fill material in "waters of the United States." As part of the permit review process, the impact of discharging dredged or fill material on wetland functions must be assessed. On 16 August 1996 a National Action Plan to Implement the Hydrogeomorphic Approach (NAP) for developing Regional Guidebooks to assess wetland functions was published. This report is the first in a series of Regional Guidebooks that will be published in accordance with the National Action Plan.

RESEARCH OBJECTIVE: The objective of this research was to develop a Regional Guidebook for assessing the functions of low gradient, riverine wetlands in western Kentucky in the context of the 404 Regulatory Program.

SUMMARY: The Hydrogeomorphic (HGM) Approach is a collection of concepts and methods for developing functional indices and subsequently using them to assess the capacity of a wetland to perform functions relative to similar wetlands in a region. The approach was initially designed to be used in the context of the Clean Water Act Section 404 Regulatory Program permit review sequence to consider alternatives, minimize impacts, assess unavoidable project impacts, determine mitigation requirements, and monitor the success of mitigation projects. However, a variety of other potential applications for the approach have been identified, including: determining minimal effects under the Food Security Act, designing mitigation projects, and managing wetlands.

This report uses the HGM Approach to develop a Regional Guidebook for assessing the functions of low gradient, riverine wetlands in western Kentucky. The report begins with a characterization of low gradient, riverine wetlands in western Kentucky, then discusses the (1) rationale used to select functions, (2) the rationale used to select model variables and metrics, (3) the rationale used to develop assessment models, and (4) the data from reference wetlands used to calibrate model variables and assessment models. Finally, it outlines an assessment protocol for using the model variables and functional indices to assess low gradient, riverine wetlands in western Kentucky.

About the Authors: Mr. William B. Ainslie is a wetland scientist with the Wetlands Protection Section of the U.S. Environmental Protection Agency, Region IV, Atlanta, GA. Mr. R. Daniel Smith is a research ecologist in the Environmental Laboratory at the U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. Mr. Bruce A. Pruitt is a watershed hydrologist with the Ecological Evaluation Section of the U.S. Environmental Protection Agency, Region IV, Athens, GA. Dr. Thomas H. Roberts is a professor of biology at Tennessee Technological University, Cookeville, TN. Mr. Earl J. Sparks is a biologist with the U.S. Army Engineer District, Louisville, Newburgh Field Office, Newburgh, IN. Dr. Larry West is a professor of soil science in the Department of Crop and Soil Sciences at the University of Georgia, Athens, GA. Dr. Gordon L. Godshalk is a professor in the Environmental Studies Program at Alfred University, Alfred, NY. Mr. Michael V. Miller is an environmental scientist with the Coastal and Wetlands Section of the Illinois State Geological Survey in Champaign, IL.

Contents

List of Figures

List of Tables

Preface

This Regional Guidebook was authorized by Headquarters, U.S. Army Corps of Engineers (HQUSACE), as part of the Characterization and Restoration of Wetlands Research Program (CRWRP). Mr. Dave Mathis, CERD-C, was the CRWRP Coordinator at the Directorate of Research and Development, HQUSACE; Ms. Colleen Charles, CECW-OR, served as the CRWRP Technical Monitor's Representative; and Dr. Russell F. Theriot, Environmental Laboratory (EL), Waterways Experiment Station (WES), was the CRWRP Program Manager. This work took place under the general supervision of Dr. Morris Mauney, Chief, Wetlands Branch, EL; Dr. Conrad Kirby, Chief, Environmental Resources Division, EL; and Dr. John Harrison, Director, EL. WES, a complex of five laboratories located in Vicksburg, MS, is part of the Engineer Research and Development Center (ERDC).

This report was prepared by Messrs. William B. Ainslie, U.S. Environmental Protection Agency (EPA) Region IV; R. Daniel Smith, EL; Bruce A. Pruitt, EPA Region IV; Earl J. Sparks, U.S. Army Engineer District, Louisville; Michael V. Miller, Illinois State Geological Survey; and by Drs. Thomas H. Roberts, Tennessee Technological University; Larry West, University of Georgia; and Gordon L. Godshalk, Alfred University, NY.

The authors wish to acknowledge the efforts of the following people, without whom this document would not have been possible: Hal Bryan, Bob Cooper, Tim Davis, Paula Gayle, Jack Grubaugh, Chris Hughes, Tasos Karathanasis, Anthony Khiel, Don Porter, Brian Reeder, Charlie Rhodes, Ray Toor, Tim Wilder, and Doug Winford, who attended the workshop and provided a great deal of thoughtful and constructive insight into the development of these models; Jeff Grubbs for his diligence in the field during the Western Kentucky Advanced Identification during which he collected much of the information for this Guidebook; Drs. Mark Brinson, Stephen Forsythe, Scott Franklin, Barb Kleiss, Richard Rheinhardt, and Dennis Whigham for reviewing various drafts of the Guidebook; Buddy Clairain, Tom Welborn, Dan Evans, and William Christman for their administrative support which allowed the time and resources necessary to complete this effort.

At the time of publication of this report, Commander of ERDC was COL Robin R. Cababa, EN.

This report should be cited as follows:

> Ainslie, W. B., Smith, R. D., Pruitt, B. A., Roberts, T. H., Sparks, E. J., West, L., Godshalk, G. L., and Miller, M. V. (1999). "A regional guidebook for assessing the functions of low gradient, riverine wetlands in western Kentucky," Technical Report WRP-DE-17, U. S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

1 Introduction

The Hydrogeomorphic (HGM) Approach is a collection of concepts and methods for developing functional indices, and subsequently using them to assess the capacity of a wetland to perform functions relative to similar wetlands in a region. The approach was initially designed to be used in the context of the Clean Water Act Section 404 Regulatory Program permit review sequence to consider alternatives, minimize impacts, assess unavoidable project impacts, determine mitigation requirements, and monitor the success of mitigation projects. However, a variety of other potential applications for the approach have been identified, including determining minimal effects under the Food Security Act, designing mitigation projects, and managing wetlands.

On 16 August 1996 a National Action Plan to Implement the Hydrogeomorphic Approach (NAP) was published (National Interagency Implementation Team 1996). The NAP was developed cooperatively by the U.S. Army Corps of Engineers (USACE), U.S. Environmental Protection Agency (USEPA), Natural Resources Conservation Service (NRCS), Federal Highways Administration (FHWA), and U.S. Fish and Wildlife Service (USFWS). Publication of the NAP was designed to outline a strategy and promote the development of Regional Guidebooks for assessing the functions of regional wetland subclasses using the HGM Approach, to solicit the cooperation and participation of Federal, State, and local agencies, academia, and the private sector in this effort, and to update the status of Regional Guidebook development.

The sequence of tasks necessary to develop a Regional Guidebook outlined in the NAP was used to develop this Regional Guidebook (see Development Phase). The National Riverine Guidebook (Brinson et al. 1995) served as the starting point for an initial workshop held at Lake Barkley State Park, KY, on 21-24 May 1996. The workshop was attended by hydrologists, biogeochemists, soil scientists, wildlife biologists, and plant ecologists from the public, private, and academic sectors with extensive knowledge of riverine, low gradient, forested wetlands in western Kentucky. Based on the results of the workshop, a regional wetland subclass was defined and characterized, a reference domain was defined, wetland functions were selected, model variables were identified, and conceptual assessment models were developed. Subsequently, field work was conducted to collect data from reference wetlands. This data was used to revise and calibrate the conceptual assessment models. A draft version of this Regional Guidebook was then subjected to several rounds of peer review and revised into the present document.

The objectives of this Regional Guidebook are to: (a) characterize the low gradient, riverine wetland in the western Kentucky reference domain, (b) provide the rationale used to select functions for the low gradient riverine regional sub-class, (c) provide the rationale used to select model variables and metrics, (d) provide the rationale used to develop assessment models, (e) provide data

from reference wetlands and document its use in calibrating model variables and assessment models, and (f) outline the necessary protocols for applying the functional indices to the assessment of wetland functions.

This document is organized in the following manner. Chapter 1 provides the background, objectives, and organization of the document. Chapter 2 provides a brief overview of the major components of the HGM Approach and the Development and Application Phases required to implement the approach. Chapter 3 characterizes the Low Gradient Riverine Subclass in western Kentucky in terms of geographical extent, climate, geomorphic setting, hydrology, vegetation, soils, and other factors that influence wetland function. Chapter 4 discusses each of the wetland functions, model variables, and functional indices. This discussion includes a definition of the function, a quantitative, independent measure of the function for the purposes of validation, a description of the wetland ecosystem and landscape characteristics that influence the function, a definition and description of model variables used to represent these characteristics in the assessment model, a discussion of the assessment model used to derive the functional index, and an explanation of the rationale used to calibrate the index with reference wetland data. Chapter 5 outlines the steps of the assessment protocol for conducting a functional assessment of Low Gradient, Riverine Wetlands in western Kentucky. Appendix A provides summaries of functions, assessment models, variables, variable measures, and copies of the field forms needed to collect field data. Appendix B provides expanded discussions on how to measure selected assessment variables. Appendix C contains the data collected at reference wetlands.

While it is possible to assess the functions of low gradient, riverine wetlands in western Kentucky using only the information contained in Chapter 5 and Appendix B, it is suggested that potential users familiarize themselves with the information in Chapters 2-4 prior to conducting an assessment.

2 Overview of the Hydrogeomorphic Approach

As indicated in Chapter 1, the HGM Approach is a collection of concepts and methods for developing functional indices and subsequently using them to assess the capacity of a wetland to perform functions relative to similar wetlands in a region. The HGM Approach includes four integral components: (a) the HGM Classification, (b) reference wetlands, (c) assessment models/functional indices, and (d) assessment protocols. During the Development Phase of the HGM Approach, these four components are integrated in a Regional Guidebook for assessing the functions of a regional wetland subclass. Subsequently, during the Application Phase, end users, following the assessment protocols outlined in the Regional Guidebook, assess the functional capacity of selected wetlands. Each of the components of the HGM Approach and the Development and Application Phases are discussed below. More extensive treatment of these topics can be found in Brinson (1993a,b; 1995a,b), Brinson et al. (1995, 1996, 1998), Smith et al. (1995), Hauer and Smith (1998), and WRP (in preparation).

Hydrogeomorphic Classification

Wetland ecosystems share a number of common attributes including relatively long periods of inundation or saturation, hydrophytic vegetation, and hydric soils. In spite of these common attributes, wetlands occur under a wide range of climatic, geologic, and physiographic situations and exhibit a wide range of physical, chemical, and biological characteristics and processes (Ferren, Fiedler, and Leidy (1996); Ferren et al. 1996a,b; Mitch and Gosselink 1993; Semeniuk 1987; Cowardin et al. 1979). The variability of wetlands makes it challenging to develop assessment methods that are both accurate (i.e., sensitive to significant changes in function) and practical (i.e., can be completed in the relatively short time frame available for conducting assessments). Existing "generic" methods, designed to assess multiple wetland types throughout the United States, are relatively rapid, but lack the resolution necessary to detect significant changes in function. However, one way to achieve an appropriate level of resolution within the available time frame is to reduce the level of variability exhibited by the wetlands being considered (Smith et al. 1995).

The HGM Classification was developed specifically to accomplish this task (Brinson 1993a). It identifies groups of wetlands that function similarly using three criteria that fundamentally influence how wetlands function. These criteria are geomorphic setting, water source, and

hydrodynamics. Geomorphic setting refers to the landform and position of the wetland in the landscape. Water source refers to the primary water source in the wetland such as precipitation, overbank floodwater, or groundwater. Hydrodynamics refers to the level of energy and the direction that water moves in the wetland. Based on these three criteria, any number of "functional" wetland groups can be identified at different spatial or temporal scales. For example, at a continental scale, Brinson (1993a,b) identified five hydrogeomorphic wetland classes. These were later expanded to the seven classes described in Table 1 (Smith et al. 1995). In many cases, the level of variability in wetlands encompassed by a continental scale hydrogeomorphic class is still too great to develop assessment models that can be rapidly applied while being sensitive enough to detect changes in function at a level of resolution appropriate to the 404 review process. For example, at a continental geographic scale the depression class includes wetlands as diverse as California vernal pools (Zedler 1987), prairie potholes in North and South Dakota (Kantrud, Krapu, and Swanson 1989; Hubbard 1988), playa lakes in the high plains of Texas (Bolen, Smith, and Schramm 1989), kettles in New England, and cypress domes in Florida (Kurz and Wagner 1953, Ewel and Odum 1984).

To reduce both inter- and intraregional variability the three classification criteria are applied at a smaller, regional geographic scale to identify regional wetland subclasses. In many parts of the country, existing wetland classifications can serve as a starting point for identifying these regional subclasses (Stewart and Kantrud 1971; Golet and Larson 1974; Wharton et al. 1982; Ferren, Fiedler, and Leidy 1996; Ferren et al. 1996a,b). Regional subclasses, like the continental classes, are distinguished on the basis of geomorphic setting, water source, and hydrodynamics. In addition, certain ecosystem or landscape characteristics may also be useful for distinguishing regional subclasses in certain regions. For example, depression subclasses might be based on water source (i.e., groundwater versus surface water) or the degree of connection between the wetland and other surface waters (i.e., the flow of surface water in or out of the depression through defined channels). Tidal fringe subclasses might be based on salinity gradients (Shafer and Yozzo 1998). Slope subclasses might be based on the degree of slope, landscape position, source of water (i.e., throughflow versus groundwater), or other factors. Riverine subclasses might be based on water source, position in the watershed, stream order, watershed size, channel gradient, or floodplain width. Examples of potential regional subclasses are shown in Table 2, Smith et al. (1995), and Rheinhardt, Brinson, and Farley (1997).

Regional Guidebooks include a thorough characterization of the regional wetland subclass in terms of its geomorphic setting, water sources, hydrodynamics, vegetation, soil, and other features that were taken into consideration during the classification process.

Reference Wetlands

Reference wetlands are the wetland sites selected to represent the range of variability that occurs in a regional wetland subclass as a result of natural processes and disturbance (e.g., succession, channel migration, fire, erosion, and sedimentation) as well as cultural alteration. The reference domain is the geographic area occupied by the reference wetlands (Smith et al. 1995). Ideally, the geographic extent of the reference domain will mirror the geographic area encompassed by the regional wetland subclass; however, this is not always possible due to time and resource constraints.

Table 1 **Hydrogeomorphic Wetland Classes at the Continental Scale**	
HGM Wetland Class	**Definition**
Depression	Depression wetlands occur in topographic depressions (i.e., closed elevation contours) that allow the accumulation of surface water. Depression wetlands may have any combination of inlets and outlets or lack them completely. Potential water sources are precipitation, overland flow, streams, or groundwater/ interflow from adjacent uplands. The predominant direction of flow is from the higher elevations toward the center of the depression. The predominant hydrodynamics are vertical fluctuations that range from diurnal to seasonal. Depression wetlands may lose water through evapotranspiration, intermittent or perennial outlets, or recharge to groundwater. Prairie potholes, playa lakes, vernal pools, and cypress domes are common examples of depression wetlands.
Tidal Fringe	Tidal fringe wetlands occur along coasts and estuaries and are under the influence of sea level. They intergrade landward with riverine wetlands where tidal current diminishes and river flow becomes the dominant water source. Additional water sources may be groundwater discharge and precipitation. The interface between the tidal fringe and riverine classes is where bidirectional flows from tides dominate over unidirectional ones controlled by floodplain slope of riverine wetlands. Because tidal fringe wetlands frequently flood and water table elevations are controlled mainly by sea surface elevation, tidal fringe wetlands seldom dry for significant periods. Tidal fringe wetlands lose water by tidal exchange, by overland flow to tidal creek channels, and by evapotranspiration. Organic matter normally accumulates in higher elevation marsh areas where flooding is less frequent and the wetlands are isolated from shoreline wave erosion by intervening areas of low marsh. *Spartina alterniflora* salt marshes are a common example of tidal fringe wetlands.
Lacustrine Fringe	Lacustrine fringe wetlands are adjacent to lakes where the water elevation of the lake maintains the water table in the wetland. In some cases, these wetlands consist of a floating mat attached to land. Additional sources of water are precipitation and groundwater discharge, the latter dominating where lacustrine fringe wetlands intergrade with uplands or slope wetlands. Surface water flow is bidirectional, usually controlled by water-level fluctuations resulting from wind or seiche. Lacustrine wetlands lose water by flow returning to the lake after flooding and evapotranspiration. Organic matter may accumulate in areas sufficiently protected from shoreline wave erosion. Unimpounded marshes bordering the Great Lakes are an example of lacustrine fringe wetlands.
Slope	Slope wetlands are found in association with the discharge of groundwater to the land surface or sites with saturated overland flow with no channel formation. They normally occur on sloping land ranging from slight to steep. The predominant source of water is groundwater or interflow discharging at the land surface. Precipitation is often a secondary contributing source of water. Hydrodynamics are dominated by downslope unidirectional water flow. Slope wetlands can occur in nearly flat landscapes if groundwater discharge is a dominant source to the wetland surface. Slope wetlands lose water primarily by saturated subsurface flows, surface flows, and by evapotranspiration. Slope wetlands may develop channels, but the channels serve only to convey water away from the slope wetland. Slope wetlands are distinguished from depression wetlands by the lack of a closed topographic depression and the predominance of the groundwater/interflow water source. Fens are a common example of slope wetlands
Mineral Soil Flats	Mineral soil flats are most common on interfluves, extensive relic lake bottoms, or large floodplain terraces where the main source of water is precipitation. They receive virtually no groundwater discharge, which distinguishes them from depressions and slopes. Dominant hydrodynamics are vertical fluctuations. Mineral soil flats lose water by evapotranspiration, overland flow, and seepage to underlying groundwater. They are distinguished from flat upland areas by their poor vertical drainage due to impermeable layers (e.g., hardpans), slow lateral drainage, and low hydraulic gradients. Mineral soil flats that accumulate peat can eventually become organic soil flats. They typically occur in relatively humid climates. Pine flatwoods with hydric soils are an example of mineral soil flat wetlands.
	(Continued)

Table 1 (Concluded)	
HGM Wetland Class	**Definition**
Organic Soil Flats	Organic soil flats, or extensive peatlands, differ from mineral soil flats in part because their elevation and topography are controlled by vertical accretion of organic matter. They occur commonly on flat interfluves, but may also be located where depressions have become filled with peat to form a relatively large flat surface. Water source is dominated by precipitation, while water loss is by overland flow and seepage to underlying groundwater. They occur in relatively humid climates. Raised bogs share many of these characteristics but may be considered a separate class because of their convex upward form and distinct edaphic conditions for plants. Portions of the Everglades and northern Minnesota peatlands are examples of organic soil flat wetlands.
Riverine	Riverine wetlands occur in floodplains and riparian corridors in association with stream channels. Dominant water sources are overbank flow from the channel or subsurface hydraulic connections between the stream channel and wetlands. Additional sources may be interflow, overland flow from adjacent uplands, tributary inflow, and precipitation. When overbank flow occurs, surface flows down the floodplain may dominate hydrodynamics. In headwaters, riverine wetlands often intergrade with slope, depressional, poorly drained flat wetlands, or uplands as the channel (bed) and bank disappear. Perennial flow is not required. Riverine wetlands lose surface water via the return of floodwater to the channel after flooding and through surface flow to the channel during rainfall events. They lose subsurface water by discharge to the channel, movement to deeper groundwater (for losing streams), and evapotranspiration. Peat may accumulate in off-channel depressions (oxbows) that have become isolated from riverine processes and subjected to long periods of saturation from groundwater sources. Bottomland hardwoods on floodplains are an example of riverine wetlands.

Table 2
Potential Regional Wetland Subclasses in Relation to Geomorphic Setting, Dominant Water Source, and Hydrodynamics

Geomorphic Setting	Dominant Water Source	Dominant Hydrodynamics	Potential Regional Wetland Subclasses	
			Eastern USA	**Western USA/Alaska**
Depression	Groundwater or interflow	Vertical	Prairie pothole marshes, Carolina bays	California vernal pools
Fringe (tidal)	Ocean	Bidirectional, horizontal	Chesapeake Bay and Gulf of Mexico tidal marshes	San Francisco Bay marshes
Fringe (lacustrine)	Lake	Bidirectional, horizontal	Great Lakes marshes	Flathead Lake marshes
Slope	Groundwater	Unidirectional, horizontal	Fens	Avalanche chutes
Flat (mineral soil)	Precipitation	Vertical	Wet pine flatwoods	Large playas
Flat (organic soil)	Precipitation	Vertical	Peat bogs; portions of Everglades	Peatlands over permafrost
Riverine	Overbank flow from channels	Unidirectional, horizontal	Bottomland hardwood forests	Riparian wetlands

Reference wetlands serve several purposes. First, they establish a basis for defining what constitutes a characteristic and sustainable level of function across the suite of functions selected for a regional wetland subclass. Second, they establish the range and variability of conditions exhibited by model variables and provide the data necessary for calibrating model variables and assessment models. Finally, they provide a concrete physical representation of wetland ecosystems that can be repeatedly observed and measured.

Reference standard wetlands are the subset of reference wetlands that perform the suite of functions selected for the regional subclass at a level that is characteristic in the least altered wetland sites in the least altered landscapes. Table 3 outlines the terms used by the HGM Approach in the context of reference wetlands.

Table 3
Reference Wetland Terms and Definitions

Term	Definition
Reference domain	The geographic area from which reference wetlands representing the regional wetland subclass are selected (Smith et al. 1995).
Reference wetlands	A group of wetlands that encompass the known range of variability in the regional wetland subclass resulting from natural processes and disturbance and from human alteration.
Reference standard wetlands	The subset of reference wetlands that perform a representative suite of functions at a level that is both sustainable and characteristic of the least human altered wetland sites in the least human altered landscapes. By definition, the functional capacity index for all functions in reference standard wetlands are assigned a 1.0.
Reference standard wetland variable condition	The range of conditions exhibited by model variables in reference standard wetlands. By definition, reference standard conditions receive a variable subindex score of 1.0.
Site potential (mitigation project context)	The highest level of function possible, given local constraints of disturbance history, land use, or other factors. Site potential may be less than or equal to the levels of function in reference standard wetlands of the regional wetland subclass.
Project target (mitigation project context)	The level of function identified or negotiated for a restoration or creation project.
Project standards (mitigation context)	Performance criteria and/or specifications used to guide the restoration or creation activities toward the project target. Project standards should specify reasonable contingency measures if the project target is not being achieved.

Assessment Models and Functional Indices

In the HGM Approach, an assessment model is a simple representation of a function performed by a wetland ecosystem. It defines the relationship between one or more characteristics or processes of the wetland ecosystem or surrounding landscape and the functional capacity of a wetland ecosystem. Functional capacity is simply the ability of a wetland to perform a function compared to the level of performance in reference standard wetlands.

Model variables represent the characteristics of the wetland ecosystem and surrounding landscape that influence the capacity of a wetland ecosystem to perform a function. Model variables are ecological quantities that consist of five components (Schneider 1994). These include: (a) a name, (b) a symbol, (c) a measure of the variable and procedural statement for

quantifying or qualifying the measure directly or calculating it from other measurements, (d) a set of values (i.e., numbers, categories, or numerical estimates (Leibowitz and Hyman 1997)) that are generated by applying the procedural statement, and (e) units on the appropriate measurement scale. Table 4 provides several examples.

Table 4
Components of a Model Variable

Name (Symbol)	Measure / Procedural Statement	Resulting Values	Units (Scale)
Redoximorphic Features (V_{REDOX})	Status of redoximorphic features/visual inspection of soil profile for redoximorphic features	present absent	unitless (nominal scale)
Floodplain Roughness (V_{ROUGH})	Manning's Roughness Coefficient (*n*) Observe wetland characteristics to determine adjustment values for roughness component to add to base value	0.01 0.1 0.21	unitless (interval scale)
Tree Biomass (V_{TBA})	Tree basal area/measure diameter of trees in sample plots (cm), convert to area (m^2), and extrapolate to per hectare basis	5 12.8 36	m^2/ha (ratio scale)

Model variables occur in a variety of states or conditions in reference wetlands. The state or condition of the variable is denoted by the value of the measure of the variable. For example, tree basal area, the measure of the tree biomass variable could be large or small. Similarly, recurrence interval, the measure of overbank flood frequency variable could be frequent or infrequent. Based on its condition (i.e., value of the metric), model variables are assigned a variable subindex. When the condition of a variable is within the range of conditions exhibited by reference standard wetlands, a variable subindex of 1.0 is assigned. As the condition deflects from the reference standard condition (i.e., the range of conditions that the variable occurs in reference standard wetland), the variable subindex is assigned based on the defined relationship between model variable condition and functional capacity. As the condition of a variable deviates from the conditions exhibited in reference standard wetlands, it receives a progressively lower subindex reflecting its decreasing contribution to functional capacity. In some cases, the variable subindex drops to zero. For example, when no trees are present, the subindex for tree basal area is zero. In other cases, the subindex for a variable never drops to zero. For example, regardless of the condition of a site, Manning's Roughness Coefficient (*n*) will always be greater than zero.

Model variables are combined in an assessment model to produce a Functional Capacity Index (FCI) that ranges from 0.0 - 1.0. The FCI is a measure of the functional capacity of a wetland relative to reference standard wetlands in the reference domain. Wetlands with an FCI of 1.0 perform the function at a level that is characteristic of reference standard wetlands. As the FCI decreases, it indicates the capacity of the wetland to perform the function is less than that which is characteristic of reference standard wetlands.

Assessment Protocol

The final component of the HGM Approach is the assessment protocol. The assessment protocol is a series of tasks, along with specific instructions, that allow the end user to assess the functions of a particular wetland area using the functional indices in the Regional Guidebook. The first task is characterization which involves describing the wetland ecosystem and the surrounding

landscape, describing the proposed project and its potential impacts, and identifying the wetland areas to be assessed. The second task is collecting the field data for model variables. The final task is analysis which involves calculation of functional indices.

Development Phase

The Development Phase of the HGM Approach is ideally carried out by an interdisciplinary team of experts known as the "Assessment Team," or "A-Team." The product of the Development Phase is a Regional Guidebook, for assessing the functions of a specific regional wetland subclass (Figure 1). In developing a Regional Guidebook, the A-Team will complete the following major tasks. After organization and training, the first task of the A-Team is to classifying the wetlands within the region of interest into regional wetland subclasses using the principles and criteria of the Hydrogeomorphic Classification (Brinson 1993a; Smith et al. 1995). Next, focusing on the specific regional wetland subclass selected, the A-Team develops an ecological characterization or functional profile of the subclass. The A-Team then identifies the important wetland functions, conceptualizes assessment models, identifies model variables to represent the characteristics and processes that influence each function, and defines metrics for quantifying model variables. Next, reference wetlands are identified to represent the range of variability exhibited by the regional subclass. Field data are then collected from the reference wetlands and used to calibrate model variables and verify the conceptual assessment models. Finally, the A-Team develops the assessment protocols necessary for regulators, managers, consultants, and other end users to apply the indices to the assessment of wetland functions. The following list provides the detailed steps involved in the general sequence described above.

Task 1: Organize the A-Team
- A. Identify A-Team members
- B. Train A-Team in the HGM Approach

Task 2: Select and Characterize Regional Wetland Subclass
- A. Identify/prioritize regional wetland subclasses
- B. Select regional wetland subclass and define reference domain
- C. Initiate literature review
- D. Develop preliminary characterization of regional wetland subclass
- E. Identify and define wetland functions

Task 3: Select Model Variables and Metrics and Construct Conceptual Assessment Models
- A. Review existing assessment models
- B. Identify model variables and metrics
- C. Define initial relationship between model variables and functional capacity
- D. Construct conceptual assessment models for deriving functional capacity indices (FCI)
- E. Complete Precalibrated Draft Regional Guidebook (PDRG)

Task 4: Conduct Peer Review of Precalibrated Draft Regional Guidebook
- A. Distribute PDRG to peer reviewers
- B. Conduct interdisciplinary, interagency workshop of PDRG
- C. Revise PDRG to reflect peer review recommendations

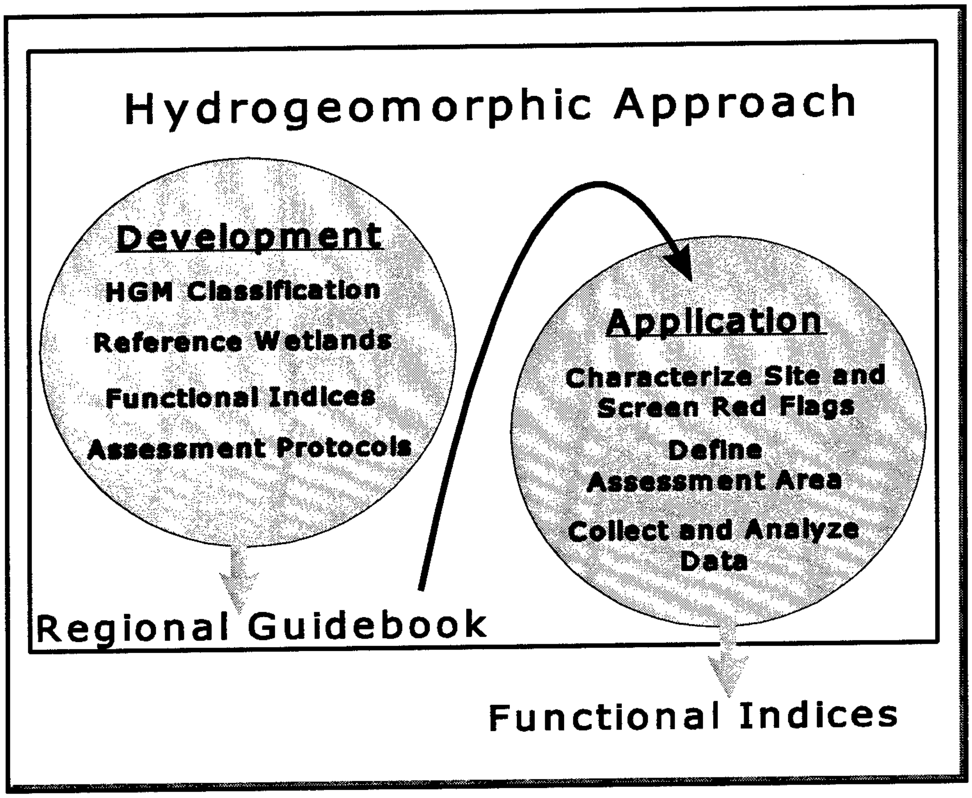


Figure 1. Development and application phases of the HGM Approach

D. Distribute revised PDRG to peer reviewers for comment
E. Incorporate final comments from peer reviewers on revisions into the PDRG

Task 5: Identify and Collect Data From Reference Wetlands
A. Identify reference wetland field sites
B. Collect data from reference wetland field sites
C. Analyze reference wetland data

Task 6: Calibrate and Field Test Assessment Models
A. Calibrate model variables using reference wetland data
B. Verify and validate (optional) assessment models
C. Field test assessment models for repeatability and accuracy
D. Revise PDRG based on calibration, verification, validation (optional), and field testing results into a Calibrated Draft Regional Guidebook (CDRG)

Task 7: Conduct Peer Review and Field Test of Calibrated Draft Regional Guidebook
A. Distribute CDRG to peer reviewers
B. Field test CDRG
C. Revise CDRG to reflect peer review and field test recommendations
D. Distribute CDRG to peer reviewers for final comment on revisions
E. Incorporate peer reviewers final comments on revisions
F. Publish Operational Draft Regional Guidebook (ODRG)

Task 8: Technology Transfer
- A. Train end users in the use of the ODRG
- B. Provide continuing technical assistance to end users of the ODRG

Application Phase

The Application Phase involves two steps. The first is using the assessment protocols outlined in the Regional Guidebook to carry out the following tasks (Figure 1).

a. Define assessment objectives

b. Characterize the project site

c. Screen for red flags

d. Define the Wetland Assessment Area

e. Collect field data

f. Analyze field data

The second step involves applying the results of the assessment, the FCI, to the appropriate decision making processes of the permit review sequence, such as alternatives analysis, minimization, assessment of unavoidable impacts, determination of compensatory mitigation, design and monitoring of mitigation, comparison of wetland management alternatives or results, determination of restoration potential, or identification of acquisition or mitigation sites.

3 Characterization of Low Gradient, Riverine Wetlands in Western Kentucky

Regional Wetland Subclass and Reference Domain

This Regional Guidebook was developed to assess the functions of frequently flooded, forested wetlands on floodplains of low gradient rivers. These wetlands are known locally, and throughout much of the southeastern United States, as bottomland hardwoods (Wharton et al. 1982). National Wetland Inventory data indicate that approximately 9 percent of Hopkins, Muhlenburg, Ohio, and Butler Counties are classified as palustrine forested wetlands which, for the most part, fall into the low gradient riverine regional wetland subclass (Figure 2).

According to Smith et al. (1995), the reference domain is the geographic area occupied by the reference wetland sites. The reference domain selected to represent this regional wetland subclass is the western Kentucky Coalfield (Figure 3). Under ideal circumstances, the reference domain that is used to develop a Regional Guidebook will mirror the full geographic extent of the regional wetland subclass. However, as in this case, it is not always possible to garner the time and resources necessary to identify the full geographic extent of a regional subclass or to sample reference wetlands throughout it. Under these circumstances, the reference domain represents a geographic subset of the full geographic extent of the regional subclass. With further investigation and field sampling, the reference domain for this regional subclass could be expanded to include other low gradient, riverine wetlands in this hydrologic reporting area (Figure 4) or ecoregion (i.e., the Interior Low Plateau, Shawnee Hills Section of the Eastern Broadleaf Forest (Continental Province)) (McNab and Avers 1994).

Description of the Regional Subclass

Physiography and geology

The Eastern Region of the Interior Coal Province covers large portions of Illinois, western Indiana, and northwestern Kentucky (Quinones, York, and Plebuch 1983). The western Kentucky Coalfield Region (Fenneman 1938) comprises the southeastern portion of the Eastern Region of the Interior Coal Province (Figure 3). This region is a structural and topographic basin

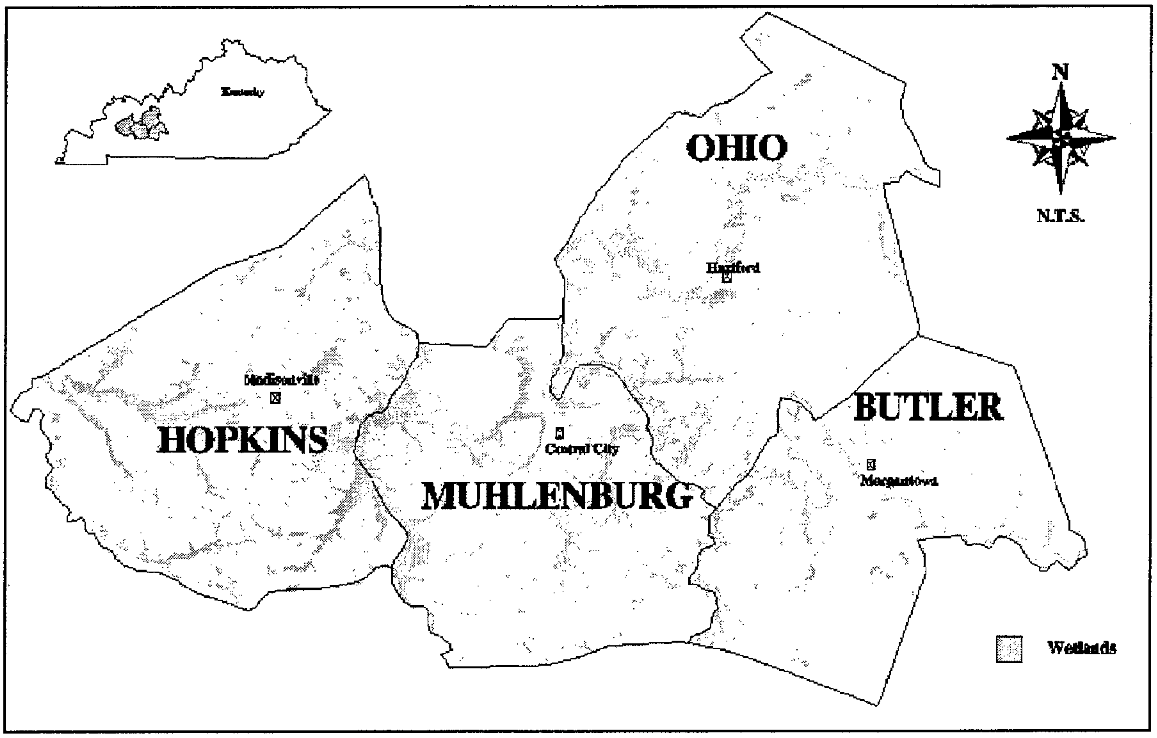


Figure 2. Palustrine forested wetlands in four western Kentucky counties based on National Wetland Inventory maps

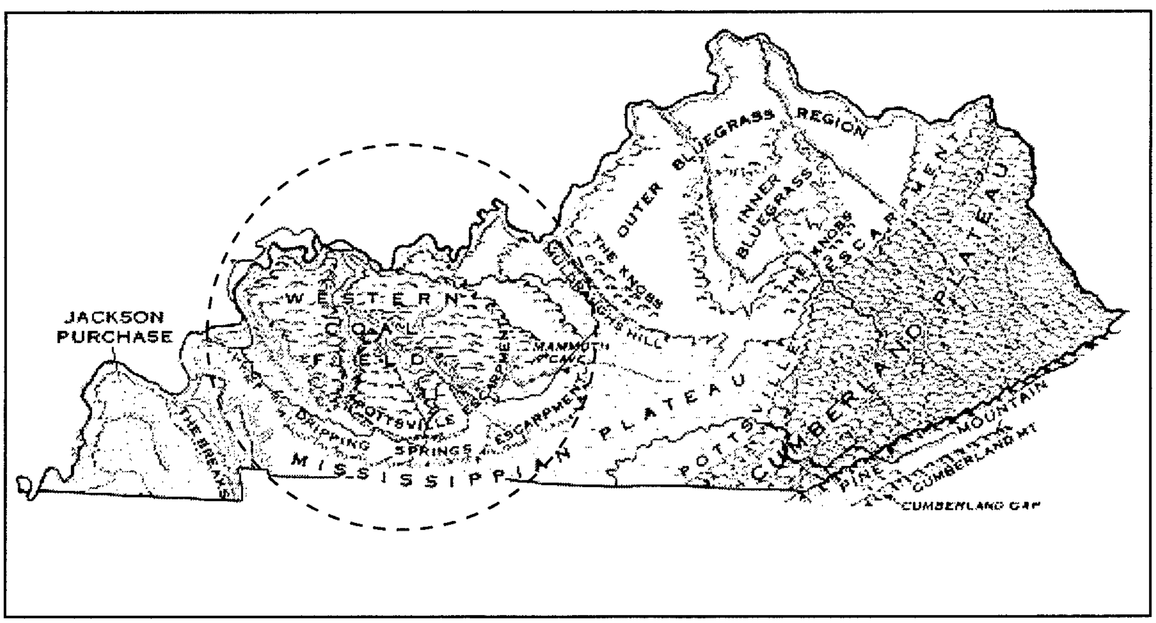


Figure 3. Western Kentucky Coalfield physiographic province

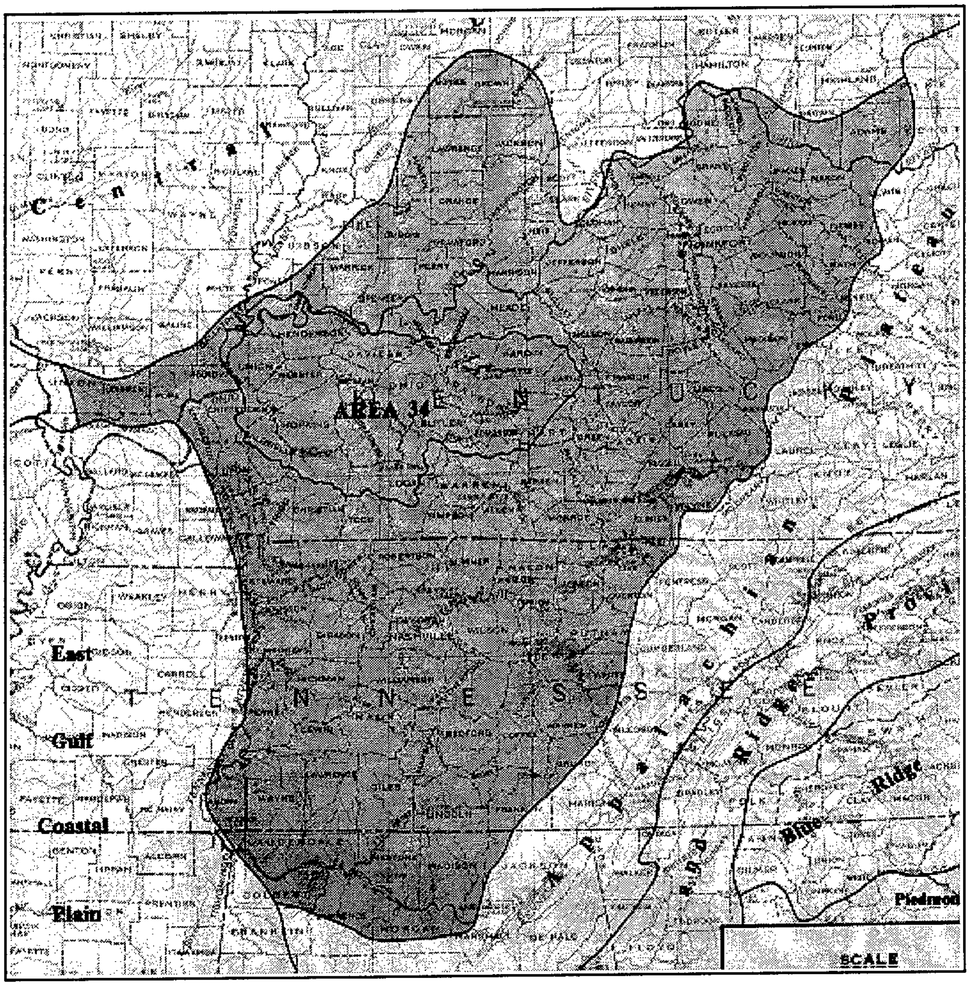


Figure 4. Area 34 hydrologic reporting area

underlain by Pennsylvanian age sandstones, conglomerates, and shales with interbedded coals and minor oil and gas fields (Choquette 1988, McGrain 1983). The outer portion of the region is characterized by steep sandstone and conglomerate cliffs, and the inner portion is a mature plateau with rolling hills and moderately wide valleys with rivers that currently serve as tributaries to the Ohio River.

During the Pleistocene, the stream valleys in this area filled with slackwater alluvium (consisting of sand, silt, and clay) due to glacial debris blocking the mainstem Ohio River. As a result of this rock dam, many western Kentucky rivers were impounded, causing the alluvial valleys to be filled with sediments, much like reservoirs today (Choquette 1988, Grubb and Ryder 1972, McGrain 1983). On some of the rivers, the ponding effect extended for miles, and the alluvial valleys were filled with up to 60 m of alluvial material characterized by unconsolidated, poorly sorted sand, silt, clay, and gravel. The lower end of the Tradewater River Basin, for example, has alluvium averaging 20 m thick (Grubb and Ryder 1972). The results of these Pleistocene events are still evident today in the broad, seemingly underfit river valleys occupied by many western Kentucky rivers (Drury 1964, 1977; McGrain 1983). The slight relief of these

wide, silt-filled river valleys create ideal conditions for the development of riparian/bottomland hardwood wetlands (Mitsch et al. 1983a).

Climate

The climate of the western Kentucky Coalfield is humid temperate (Grubb and Ryder 1972). Annual precipitation averages 1.17 m (46 in.) (Quinones, York, and Plebuch 1983) and mean annual temperature for the region is 14 °C (57°F). Local climatic conditions are a result of warm, moist maritime air masses from the Gulf of Mexico mixing with cold, dry continental air masses. This produces a great deal of seasonal variability in precipitation with an average of 0.34 m (13.5 in.) in spring, 0.31 m (12.4 in.) in summer, 0.25 m (10 in.) in fall, and 0.29 m (11.5 in.) in winter (Grubb and Ryder 1972, Choquette 1988). Winter precipitation results largely from frontal storm systems, and summer precipitation comes from convective storm activity. Mean monthly precipitation is exceeded by potential evapotranspiration (PET) from June through September (Grubb and Ryder 1972). These variations in precipitation, temperature, and PET affect river discharge and other surface and subsurface sources that supply water to low gradient, riverine wetlands.

Basin characteristics

The Eastern Region of the Interior Coal Province is divided into 11 hydrologic reporting areas based upon drainage boundaries, location of basins, size, hydrologic characteristics, and mining activities (Quinones, York, and Plebuch 1983). Area 34 includes the western Kentucky Coalfield (Figure 4). Basin characteristics such as shape, size, relief, and drainage density geomorphically distinguish watersheds and influence the hydrologic regime in riverine wetlands. The reference domain contains all or portions of the Tradewater, Pond, Rough, and Green River watersheds. These watersheds are generally elongate in shape which tends to lower hydrograph peaks and sustain stream flows over longer durations (Choquette 1988; Patton 1988; Ritter, Kochel and Miller 1995). Ritter, Kochel, and Miller (1995) point out that the basin measures of size, ruggedness, and drainage density are highly variable from region to region. However, these characteristics are useful for characterizing basins with similar climate and geology and for providing information on how those characteristics affect flood flows which inundate riverine wetlands. Relief, represented by the "ruggedness number," summarizes the relationship between relief and drainage density (Melton 1958, Patton and Baker 1976, Patton 1988). Basins with high ruggedness have a greater potential for flash flooding than basins with low ruggedness. Drainage density, the total length of streams per drainage area, indicates the efficiency of a watershed to convey water. Basins with high drainage densities concentrate runoff and stormflow quickly and show a rapid hydrograph response (Patton 1988). Low drainage densities indicate greater infiltration, and, consequently, hydrographs show a lower and slower response. Basin size, relief, and stream drainage density estimates are given in Table 5 for the Tradewater, Pond, Rough, and Green River watersheds where reference wetland sites occur.

The watershed characteristics of these four rivers are very similar and can, in general, be described as having moderate to low dissection, low relief, and consequently "sluggish" hydrographs (Ritter, Kochel, and Miller 1995). The hydrograph from the Tradewater River is typical for many of the river systems which have flood peaks that subside slowly, contributing to water

Table 5 Basin Characteristics of Four Western Kentucky Watersheds			
Basin	**Size, km^2**	**Ruggedness Number, drainage density x relief**	**Drainage Density, km/km^2**
Tradewater	2449	0.22	1.13
Pond	2077	0.23	1.05
Rough	2825	0.27	0.82
Green	5360	0.27	0.80

storage in associated riverine wetlands (Grubb and Ryder 1972; Quinones, York, and Plebuch 1983).

Fluvial geomorphology

The riverine wetlands in this regional subclass are associated with 2nd, 3rd, and 4th order streams (Strahler 1952) based on U.S. Geological Survey 1:24,000 topographic maps. Valley and basin characteristics give rise to stream types with typical form, pattern, and dimensions. The valley type associated with Class C streams in the western Kentucky Coalfield is Valley type VIII (Rosgen 1996). Rosgen identifies this valley landform as having multiple river terraces positioned laterally along broad valleys with gentle, down-valley gradients. In the western Kentucky Coalfield, valleys are broad with low gradients; however, multiple terraces are not evident. Valley type VIII soils are developed predominantly over alluvium originating from combined riverine and lacustrine depositional processes.

The predominant unaltered stream type, which occurs adjacent to riverine wetlands in this subclass, can be classified as C6 using Rosgen's (1994) classification scheme. Generally, these streams have gradients less than 2 percent, are relatively sinuous (i.e., ratio of stream length (measured along the center of the channel) to valley length (measured along the axis of the valley)), and have bedform morphology indicative of a riffle/pool configuration (Rosgen 1996). These streams are generally slightly entrenched, meandering, silt-clay dominated, riffle-pool channels with well-developed floodplains. This stream type is prevalent in the broad, low relief valleys with a history of lacustrine deposition such as is found in the western Kentucky Coalfield.

The floodplain, of which these low gradient riverine wetlands are a part, can also be generally classified as a Class C floodplain formed by frequently recurring flood events along a laterally stable, single threaded, low gradient channel (Nanson and Croke 1992). Stream power associated with these streams is low (generally $<10\ Wm^{-2}$) and sediments of these systems are typically silts and clays. Low stream power and silty-clay sediments give rise to vertically accreted, flat floodplains with prevalent back-swamps (Nanson and Croke 1992).

Altered streams (e.g., channelized) in the Coalfield fall into the Class F stream (Rosgen 1994). These streams occur in Valley type VIII and can be characterized as "entrenched, meandering." Class F streams are deeply incised in valleys of relatively low elevational relief containing highly weathered rock and/or erodible material. These streams have very high channel width/depth ratios at the bankfull stage and bedforms occurring as a moderated riffle/pool

sequence. Class F stream channels can develop very high bank erosion rates, lateral extension rates, significant bar deposition, and accelerated aggradation and/or degradation while transporting and storing high sediment loads (Rosgen 1996).

Hydrologic regimes

The interaction of climate, basin/watershed, channel, and site-specific characteristics affect the magnitude, frequency, and duration of water moving through the basin which, in turn, affects where low gradient, riverine wetlands occur. Long-term temperature, precipitation regime, and other climatic factors influence the rate at which water is delivered and lost from a watershed. Basin characteristics, such as shape, size, slope, geology, etc., affect how water and sediment move through the watershed and over what period of time. As indicated, watersheds in the reference domain are generally elongate in shape, greater than 2590 km^2 (1000 square miles) in size, have low slopes (0.01- 0.05 percent; 0.3-0.9 m (1-3 ft)/mile), moderate relief, and low drainage densities which contribute to slowly rising flood stages, broad hydrograph peaks, and slow recession.

In a report on regional flood characteristics for Kentucky, Choquette (1988) states that precipitation patterns strongly influence the magnitude and frequency of floods. Seasonally changing conditions, such as evapotranspiration, antecedent soil moisture, and the extent, duration, and intensity of storm systems, influence flood response. Typically, annual maximum discharge occurs most frequently in March. Presumably this is due to low PET rates which occur prior to spring leaf-out (i.e., the growing season), leading to saturated soil conditions which in turn result in greater surface runoff and subsurface discharge which culminate in flood conditions. In basins with a drainage area of 129-2590 km^2 (50-1000 square miles), the annual maximum peaks occurred between January and April. Precipitation patterns in smaller (<129 km^2 (<50 square miles)) basins indicate that high intensity, short duration, convective summer storms cause flooding as a result of storms with limited areal extent. Conversely, low intensity, high duration, frontal storms in the winter and spring cause flooding in larger basins.

In general, wetlands in this regional subclass are saturated and/or inundated frequently (i.e., annually) and for durations long enough to develop and sustain wetland conditions (i.e., typically greater than 1 week). The saturated soil conditions, which contribute to flooding, also contribute to the maintenance of subsurface hydrology, biogeochemistry, and habitat functions in these low gradient riverine wetlands. Therefore, it is the combination of surface and subsurface hydrology that provides the water source and hydrodynamics for this wetland subclass.

Soils

Soils in reference wetlands on the floodplains of the Tradewater, Pond, Rough, and Green Rivers are generally deep, nearly level, moderately well to poorly drained, and medium to fine textured. The soil associations found on low gradient, riverine floodplains in western Kentucky include Karnak-McGary-Belknap, Bonnie-Karnak, Stendal-Bonnie-Steff, Melvin-Newark-Karnak, Melvin-Karnak-McGary, Belknap-Waverly, and Newark- Otwell-Melvin (USDA 1977, 1980, 1987). These soils generally occur on 0.0-0.02 percent slopes, have slow to moderate permeability, and slow runoff rates. The depth of these soils is between 101-152 cm (40-60 in.), and organic matter content is low. Bonnie, Karnak, Waverly, McGary, Stendal, and Melvin soils are

listed on the Natural Resources Conservation Service (NRCS) county hydric soils list. Formation and landscape position for these soil associations is described below.

a. *Karnak-McGary-Belknap.* This soil association lies on nearly level floodplains and stream terraces. The dominant soils were formed in clayey, slack-water deposits (Karnak and McGary) and in loamy alluvium high in silt content (Belknap). Regular flooding keeps these soils wet.

b. *Bonnie-Karnak.* This soil association lies on nearly level and narrow floodplains. The dominant soils were formed in alluvium and in clayey, slack-water deposits. Bonnie soils were formed in alluvium while the Karnak soils were formed in clayey, slack-water deposits. Regular flooding keeps these soils wet.

c. *Stendal-Bonnie-Steff.* This soil association is characterized by nearly level soils in valleys adjacent to uplands. The soils formed in alluvium washed from soils that formed in loess on uplands. During heavy rains the streams overflow, flooding these soils. These soils are silt loam throughout the profile and have a seasonal high water table within 30.4 cm (12 in.) of the surface.

d. *Melvin-Newark-Karnak.* This soil association consists of nearly level soils on floodplains and valleys which formed in mixed alluvium (Melvin and Newark) and clayey, slack-water alluvium (Karnak). During heavy rains the rivers and streams adjacent to these soils overflow and flood most of this association.

e. *Melvin-Karnak-McGary.* This soil association consists of soils on nearly level floodplains and stream terraces which formed in old slack-water alluvium and in alluvium that washed from limestone. The Melvin and Karnak soils are found on floodplains and the McGary soils are found on stream terraces that, in Muhlenburg County, seldom flood. Karnak soils are clayey throughout the profile, Melvin soils are loamy throughout, and McGary soils are loamy in the surface layer and clayey in the subsoil.

f. *Belknap-Waverly.* This soil association consists of soils on floodplains of valleys near uplands. The soils formed in alluvium washed from upland soils that formed in loess. These soils are silt loam throughout the profile and are deep, nearly level soils with a seasonal high water table within 30.4 cm (12 in.) of the surface.

Forest vegetation communities

The western Kentucky Coalfield is part of the Central Hardwood Region (Braun 1964). Two forest community types occur on the floodplains of low gradient rivers in this region. These include the Bottomland Oak Group and the Sweetgum Group (Fralish 1994). The Bottomland Oak Group is composed primarily of swamp white (*Quercus bicolor*), swamp chestnut (*Q. michauxii*), overcup (*Q. lyrata*), bur (*Q. macrocarpa*), cherrybark (*Q. pagoda*), and Shumard (*Q. shumardii*) oaks, shellbark hickory (*Carya laciniosa*), water hickory (*C. aquatica)*, and pecan (*C. illinoiensis*). Red maple (*Acer rubrum*), green ash (*Fraxinus pennsylvanica)*, and bluebeech (*Carpinus caroliniana*) are minor community components. This forest community type occurs in the middle to upper end of the floodplain moisture gradient under a hydrologic regime that has been described as temporarily flooded (Cowardin et al. 1979, Mitsch et al. 1983). This

hydrologic regime is characterized by extended periods of inundation or saturation during the nongrowing season, but little, if any, inundation or saturation during the growing season. This forest community type occurs most commonly on Bonnie, Karnak, Melvin, and Waverly soils of silt-loam texture. Most of the species in this forest community type have low to intermediate shade tolerance, although oak and hickory may survive in the understory, growing slowly until large canopy gaps develop. Due to logging and clearing for agriculture, reference standard sites represent some of the few remaining mature stands of this forest community type in the western Kentucky Coalfield.

The Sweetgum Group is composed of sweetgum (*Liquidambar styraciflua*), sycamore (*Platanus occidentalis*), river birch (*Betula nigra)*, green ash (*Fraxinus pennsylvanica*), black willow (*Salix nigra*), and silver maple (*Acer saccharinum*). Pin oak (*Q. palustris*) can be a minor component. This forest community type occurs at the wetter end of the floodplain moisture gradient under a hydrologic regime described as seasonally or semi-permanently flooded (Cowardin et al. 1979, Mitsch et al. 1983). This hydrologic regime is characterized by extended periods of inundation or saturation during the nongrowing season and potentially well into the growing season. In some areas, surface water or saturation is present throughout the growing season. This forest community type occurs on Bonnie, Karnak, and Melvin soils with a silty-clay texture. These tree species tend to be very shade intolerant and form stands which have open canopies.

Vegetation surveys during sampling of reference wetlands during the development of the Regional Guidebook found most stands dominated by overcup, willow (*Q. phellos*), pin, swamp white, and cherry-bark oaks, shellbark hickory, sweet gum, red maple, silver maple, sugarberry (*Celtis laevigata*), green ash, river birch, and sycamore to be the most common in the reference domain which, in terms of species composition, corresponds closely to the temporarily flooded wetland forest type.

Cultural alteration of rivers, floodplains, and the landscape

Common cultural alterations in the western Kentucky Coalfield that affect this regional wetand subclass are coal mining, agriculture and silviculture, and channelization (Mitsch et al 1982). Surface coal mining is one of the dominant land uses in the area with production concentrated in Hopkins, Muhlenburg, and Ohio Counties. Surface mines vary in size from small operations exploiting seams on hillsides to area-wide strip mining which can cover several hundred hectares (Harker et al. 1981). Surface mining can alter the hydrologic environment of adjacent wetlands and aquatic areas by increasing runoff and sedimentation. Mining activities such as vegetation removal, excavation, and dumping of large volumes of unconsolidated spoil material create unstable areas which readily erode and contribute additional sediment to streams, channels, and floodplains (Quinones, York, and Plebuch1983). Coal mining continues to be a major land disturbance throughout the study area; however, if areas are contemporaneously and effectively reclaimed, many of these erosive effects can be minimized.

Acid mine drainage is also a persistent and widespread problem in area streams. For instance, the Clear Creek watershed has been characterized as the most severely mine-impacted watershed in western Kentucky (Mitsch et al. 1983). Effluent from some of these mines can be seen on aerial photography discharging into Clear Creek wetlands. Grubb and Ryder (1972) identified Clear Creek as a major contributor of acid mine drainage to the Tradewater River. They characterized the water as calcium-magnesium-sulfate type and noted that the creek flowed

year-round as a result of in-flow from mining activities. Harker et al. (1981) reported better water quality at the mouth of Clear Creek than upstream, presumably because the extensive wetland complex was ameliorating mining impacts by storing and diluting the constituents of acid mine drainage. In addition to mining, the Clear Creek wetland system has also been altered by highway obstructions and beaver activity which have impounded water resulting in timber die-off and development of permanently flooded, emergent-vegetation-dominated wetlands. Similar effects of acid mine drainage are found in the Pond River watershed, particularly in the Drakes, Flat, and Cypress Creek subwatersheds.

Approximately 40 percent of the land in western Kentucky Coalfield is in agriculture, about 35 percent is forested, and about 16 percent is pasture (Quinones, York, and Plebuch 1983). Mitsch et al. (1982) report that as of 1981 an increase in clearing of bottomlands of 5 percent had been documented. Many low gradient, riverine wetlands in the region have been converted to agriculture. For instance, Harker et al. (1981) reported that bottomlands adjacent to Muddy Creek in Ohio County were devoted to agriculture, with little of the forested wetland or stream channel habitat remaining. This clearing for agriculture is common in the Rough and Green River watersheds. Agricultural activity affects low gradient, riverine wetlands directly through conversion and indirectly through increased runoff which contains high concentrations of sediments, nutrients, and pesticides.

Channelization affects low gradient, riverine wetlands adjacent to streams by reducing flood frequency and mineral nourishment (Mitsch et al. 1982). Alternatively, channelization can increase the duration of flooding or ponding in an adjacent wetland due to spoil banks operating as artificial levees which prevent water from receding back into the channel. In both cases, the surface and subsurface hydroperiod of the wetland is altered which consequently affects hydrologic, biogeochemical, and habitat functions. Many of the streams in the western Kentucky Coalfield have been channelized.

4 Wetland Functions and Assessment Models

The following functions performed by low gradient, riverine wetlands in western Kentucky were selected for assessment.

a. Temporarily Store Surface Water

b. Maintain Characteristic Subsurface Hydrology

c. Cycle Nutrients

d. Remove and Sequester Elements and Compounds

e. Retain Particulates

f. Export Organic Carbon

g. Maintain Characteristic Plant Community

h. Provide Habitat for Wildlife

The following sequence is used to present and discuss each of these functions:

Definition: defines the function and identifies an independent quantitative measure that can be used to validate the functional index.

Rationale for selecting the function: provides the rationale for why a function was selected and discusses onsite and offsite effects that may occur as a result of lost functional capacity.

Characteristics and processes that influence the function: describes the characteristics and processes of the wetland and the surrounding landscape that influence the function and lay the groundwork for the description of model variables.

Description of model variables: defines and discusses model variables and describes how each model variable is measured.

Functional capacity index: describes the assessment model from which the functional capacity index is derived and discusses how model variables interact to influence functional capacity.

Function 1: Temporarily Store Surface Water

Definition

Temporarily Store Surface Water is defined as the capacity of a riverine wetland to temporarily store and convey floodwaters that inundate riverine wetlands during overbank flood events. Most of the water that is stored and conveyed originates from an adjacent stream channel. However, other potential sources of water include: (a) precipitation, (b) surface water from adjacent uplands transported to the wetland via surface channels or overland flow, and (c) subsurface water from adjacent uplands transported to the wetland as interflow or shallow groundwater and discharging at the edge or interior of the floodplain. A potential independent, quantitative measure for validating the functional index is the volume of water stored per unit area per unit time (m^3/ha/time) at a discharge that is equivalent to the average annual peak event.

Rationale for selecting the function

The capacity of riverine wetlands to temporarily store and convey floodwater has been extensively documented (Dewey and Kropper Engineers 1964; Campbell and Johnson 1975; Dybvig and Hart 1977; Novitski 1978; Thomas and Hanson 1981; Ogawa and Male 1983, 1986; Demissie and Kahn 1993). Many benefits related to the reduction of flood damage occur as a result of wetlands performing the function. For example, wetlands can reduce the velocity of the flood wave and, as a result, reduce peak discharge downstream. Similarly, wetlands can reduce the velocity of water currents and, as a result, reduce damage from erosion forces (Ritter, Kochel, and Miller 1995).

In addition to these direct benefits, there are a number of ecological processes that occur in riverine wetlands that depend on the periodic inundation that results from overbank floods. For example, as the velocity of the overbank flow is reduced, inorganic sediments and particulate organic matter settle out of the water column (Nicholas and Walling 1996; Walling, Quine, and He 1992; James 1985; Ritter, Kinsey, and Kauffman 1973). This provides a nutrient subsidy to plant communities on the floodplain and can contribute to an improvement in the quality of water in streams and rivers (Mitsch, Dorge, and Wiemhoff 1979). As floodwater inundates riverine wetlands, it also provides access to floodplain feeding and reproductive areas for fish and other aquatic organisms (Copp 1997; Kilgore and Baker 1996; Copp 1989; Fremling et al. 1989; Junk, Bayley, and Sparks 1989; Scott and Nielson 1989; Ross and Baker 1983; Guillory 1979; Welcomme 1979; Gunderson 1968) and serves as a transport mechanism for plant propagules which may be important to the dispersal and regeneration of certain plant species (Johansson, Nilsson, and Nilsson 1996; Nilsson, Gardfjell, and Grelsson 1991; Schneider and Sharitz 1988). Finally, overbank floodwater facilitates the export of particulate and dissolved organic carbon from the riverine wetland to downstream aquatic food webs (Anderson and Sedell 1979, Mulholland and Kuenzler 1979).

Characteristics and processes that influence the function

The characteristics and processes that influence the capacity of a wetland to temporarily store floodwater are related to climate, watershed characteristics, and conditions in the stream channel adjacent to the wetland, as well as conditions in the wetland itself. In general, the intensity, duration, and areal extent of precipitation events affect the magnitude of the stormflow response. Typically, the higher the intensity, the longer the duration, and the greater the areal extent of a particular rainfall event, the greater the flood peak. Watershed characteristics such as size and shape, channel and watershed slopes, drainage density, and the presence of wetlands and lakes have a pronounced effect on the stormflow response (Brooks et al. 1991; Dunne and Leopold 1978; Ritter, Kochel, and Miller 1995; Leopold 1994; Patton 1988). The larger the watershed, the greater the volume and peak of streamflow for rainfall events. Watershed shape affects how quickly surface and subsurface flows reach the outlet to the watershed. For example, a round-shaped watershed concentrates runoff more quickly than an elongated one and will tend to have higher peak flows. Steeper hillslopes and channel gradients also result in quicker response and higher peak flows. The higher the drainage density (i.e., the sum of all the channel lengths divided by the watershed area), the faster water is concentrated at the watershed outlet and the higher the peak. As the percentage of wetland area and/or reservoirs increases, the greater the flattening effect (attenuation of) on the stormflow hydrograph. In general, these climatic and watershed characteristics are the same in a given region and are considered constant for the purposes of rapid assessment. However, site-specific characteristics of riverine wetlands can vary and are the emphasis of this function.

Depth, frequency, and duration of flooding in the wetland are the manifestation of the watershed stormflow response and the characteristics mentioned above. Conditions conducive to flooding are dictated, to a large degree, by the nature of the stream channel and its floodplain. The morphology of the stream channel and its floodplain reflect the discharges and sediment loads that have occurred in the past. Under stable flow and sediment conditions, the stream and its floodplain will eventually achieve equilibrium. Alteration to the stream channel or its watershed may cause instability that results in channel aggradation or degradation and a change in depth, frequency, and duration of overbank flow events (Dunne and Leopold 1978; Rosgen 1994). As the stream channel aggrades, available water storage in the channel decreases, resulting in greater depth, frequency, and duration of flooding and an increase in amount of surface water stored in the wetland over an annual cycle. Conversely, as the stream channel degrades, available water storage in the channel increases, resulting in less depth, frequency, and duration of flooding and a decrease in the amount of surface water stored in the wetland over an annual cycle. The duration of water storage is secondarily influenced by the slope and roughness of the floodplain. Slope refers to the gradient of the floodplain across which floodwaters flow. Roughness refers to the resistance to flow created by vegetation, debris, and topographic relief. In general, duration increases as roughness increases and slope decreases.

Description of model variables

Overbank Flood Frequency (V_{FREQ}). This variable represents the frequency at which water from a stream overtops its banks (i.e., exceeds channel-full discharge) and inundates riverine wetlands on the floodplain. Overbank flood frequency at the scale of the riverine wetland reflects upstream watershed and channel conditions. In the context of this function, overbank

flood frequency indicates how often peak seasonal discharges inundate a riverine wetland and allow surface water to be temporarily stored.

Recurrence interval, in years, is used to quantify this variable. Recurrence interval correlates to some degree with depth and duration of flooding, two measures that allow a more accurate and precise estimate of temporary surface water storage. However, obtaining these data for a particular riverine wetland requires considerably more time and effort than are typically available under a rapid assessment scenario. Several methods are available for more rapidly estimating recurrence interval.

(1) Determine recurrence interval using one of the following methods. Specific guidelines are provided in Appendix C:
  (a) data from a nearby stream gage
  (b) regional flood frequency curves developed by local and State offices of USACE, USGS-Water Resources Division, State Geologic Surveys, or NRCS (Jennings, Thomas, and Riggs 1994)
  (c) hydrologic models such as HEC-2 (USACE 1981, 1982), HECRAS (USACE 1997), or HSPF (Bicknell et al. 1993)
  (d) local knowledge
  (e) a regional dimensionless rating curve
(2) Report recurrence interval in years.

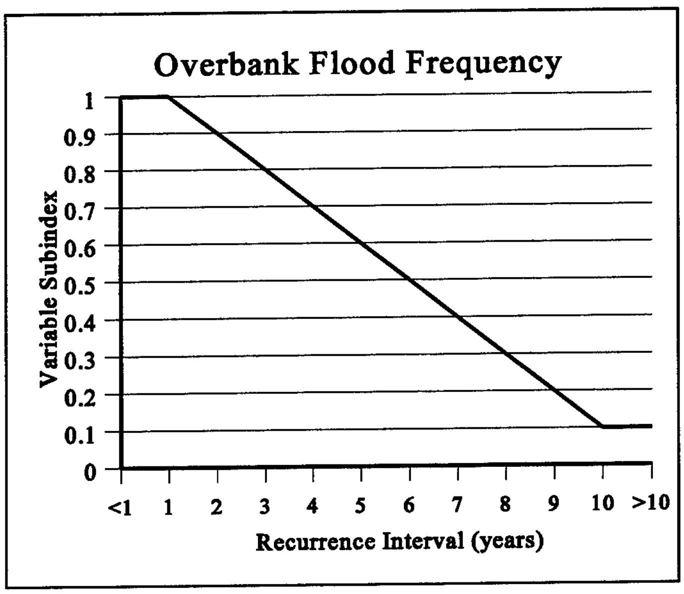


Figure 5. Relationship between recurrence interval and functional capacity

In western Kentucky reference wetlands, using the regional dimensionless curve approach described in Appendix C, recurrence interval ranged from 1-25 years (Appendix D). Based on the range of values from reference standard sites, a variable subindex of 1.0 is assigned to recurrence intervals ≤1.0 year (Figure 5). Longer recurrence intervals are assigned a linearly decreasing subindex down to 0.1 at a recurrence interval of 10 years. This is based on the assumption that where entrenchment, channelization, or levees effectively increase the depth of the stream channel, a greater discharge is required to overtop the bank and inundate the riverine wetland. Since greater discharges occur less frequently, the volume of surface water temporarily stored in riverine wetlands is less than that characteristically stored at reference standard sites in both the short and long term. The rationale for the rate at which the subindex drops to 0.1 (i.e., 1.0 to 0.1) is based on the assumption that, as frequency increases, the capacity of the wetland to store annual peak discharges decreases to one-tenth the amount of water stored over a period of 10 years under reference standard conditions. Model validation will help to define the actual nature of this relationship. Recurrence intervals >10 years are

assigned a subindex of 0.1, based on the assumption that even at longer recurrence intervals, riverine wetlands provide some floodwater storage, albeit infrequently.

Floodplain Storage Volume (V_{STORE}). This variable represents the volume that is available for storing surface water during overbank flood events. In western Kentucky, the loss of storage volume is usually a result of levees, roads, or other man-made structures that reduce the effective width of the floodplain at least below the design discharge. In the context of this function, this variable is designed to detect changes in storage volume that result from these types of structures.

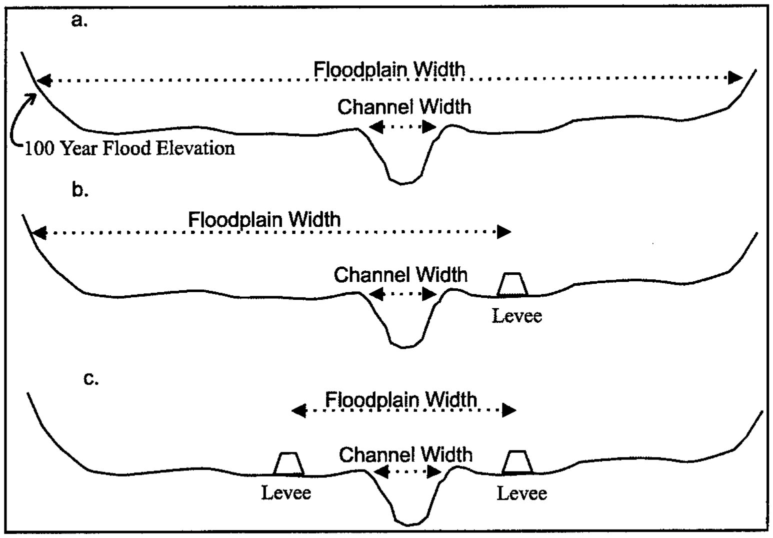


Figure 6. Determining floodplain width and channel width

The ratio of floodplain width to channel width is used to quantify this variable. Floodplain width is defined as the distance between the 100-year flood elevation contour lines on opposite sides of the stream measured perpendicular to the channel (Figure 6a). Where artificial levees, or roads that function as levees, occur, floodplain width is the distance between the riverside toe of the levee or road and the 100-year flood elevation contour (Figure 6b) or the riverside toe of a levee or road on the opposite side of the stream (Figure 6c). Channel width is defined as the distance between the top of the channel banks measured perpendicular to the channel (Figure 6). As the ratio decreases, floodplain storage volume decreases.

Measure the ratio of floodplain width to channel width with the following procedure.

(1) Measure the width of the floodplain and the width of the channel using surveying equipment or by pacing in the field. A crude estimate can be made using topographic maps or aerial photos, remembering that short distances on maps and photographs translate into long distances on the ground (i.e., the width of a section line on a 1:24,000 USGS topographic map represents about 9.1 m (30 ft) on the ground).

(2) Calculate the ratio by dividing the floodplain width by the channel width.

(3) Report the ratio of floodplain width to channel width as a unitless number.

In western Kentucky reference wetlands, the ratio of floodplain width to channel width ranged from 8 to 360 (Appendix D). Based on the range of values at reference standard wetlands, a variable subindex of 1.0 is assigned to ratios ≥55 (Figure 7). Smaller ratios are assigned a linearly decreasing subindex down to zero at a ratio of 1. This is based on the assumption that ratio of floodplain width to channel width is linearly related to the capacity of riverine wetlands to temporarily store surface water.

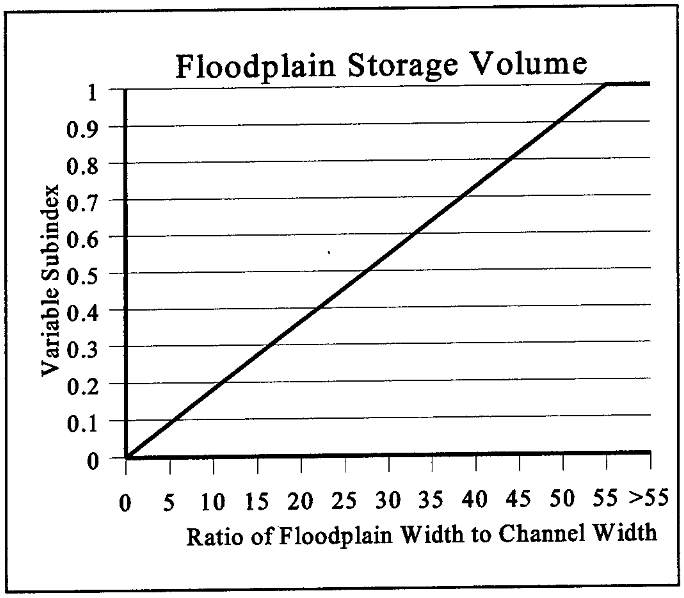


Figure 7. Relationship between the ratio of floodplain width to channel width and functional capacity

Floodplain Slope (V_{SLOPE}). This variable represents the longitudinal slope of the floodplain in the vicinity of the riverine wetland. The relationship between slope and the temporary storage of surface water is based on the proportional relationship between slope and velocity in Manning's equation (1):

$$V = \frac{1.49 \times R^{2/3} \times S^{1/2}}{n} \tag{1}$$

where

V = mean velocity of flow (ft/s)

R = hydraulic radius (ft)

S = slope (ft/ft)

n = roughness coefficient

Generally, the flatter the slope, the slower the water moves through the riverine wetland. In the context of this function, the variable is only likely to change significantly when the slope of the floodplain has been altered by surface mining, the placement of structures in the channel, or other slope altering activities.

Percent floodplain slope is used to quantify this variable. Measure it with the following procedure.

(1) Determine the change in elevation between two points along the floodplain center line (i.e., center line of the meander belt of the active channel) on a river reach representative of the area being assessed (Figure 8). This can be accomplished using the contour lines on a standard 7.5 minute USGS topographic map. The distance between the two points should be great enough so that local anomalies in floodplain slope do not influence the result. As a rule of thumb, the line between the two points should intersect at least two contour lines on a 1:24,000 scale (7.5 minute) USGS topographic map (Figure 8).

(2) Determine the straight line distance between the two points.

(3) Divide the change in elevation by the distance between the two points. For example, if the change in elevation between the two points is 3.0 m (10 ft) and the distance between the two points is 1.6 km (1 mile), the slope is 3.0 m /1000 m = 0.002.

(4) Convert the slope to a percent slope by multiplying by 100.

(5) Report floodplain slope as a percent.

In western Kentucky reference wetlands, floodplain slopes ranged from 0.03-0.3 percent (Appendix D). Reference standard wetland sites had floodplain slopes ranging from 0.03-0.05 percent. However, more extensive data from Wetzel and Bettandorff (1983) indicate that higher order rivers in western Kentucky typically have slopes ranging from 0.06-0.09 percent (0.9-1.5 m (3-5 ft)). Based on the range of values at reference standard wetlands and the additional data from Wetzel and Bettandorff (1983), a variable subindex of 1.0 is assigned to floodplain slopes ≤0.09 percent (Figure 9). As floodplain slope increases, a linearly decreasing subindex is assigned down to 0.1 at a slope of 0.23 percent. This is based on the assumption that the relationship between floodplain slope and the capacity to temporarily store surface water is linear. Floodplain slopes ≥0.23 percent are assigned a subindex of 0.1. This is because regardless of how steep the floodplain slope is, surface water will always be stored temporarily during overbank events, albeit for a short period of time.

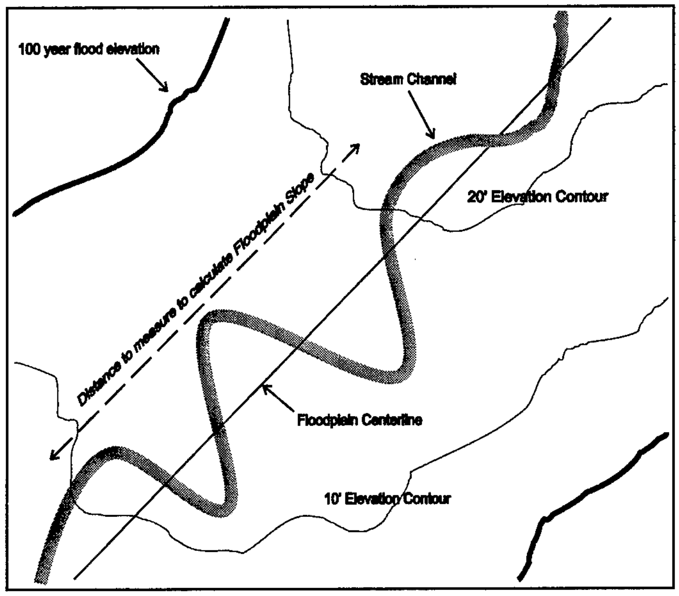


Figure 8. Measuring floodplain slope

Floodplain Roughness (V_{ROUGH}). This variable represents the resistance to the flow of surface water resulting from physical structures on the floodplain. The relationship between roughness and the velocity of surface water flow is expressed by Manning's equation which indicates that as roughness increases, velocity decreases and storage time increases (Equation 1). Several factors contribute to roughness, including the soil surface, surface irregularities (e.g., micro- and macrotopographic relief), obstructions to flow (e.g., stumps and coarse woody debris), and resistance due to vegetation structure (trees, saplings, shrubs, and herbs). Depth of flow is also an important consideration in determining roughness because

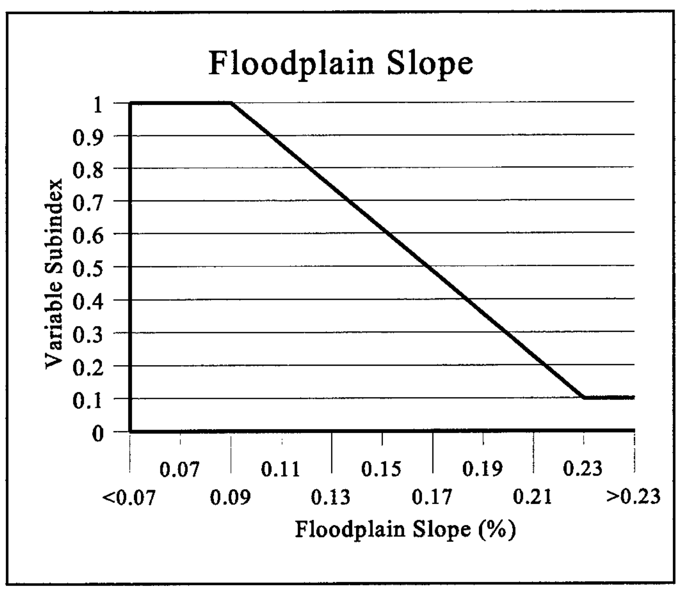


Figure 9. Relationship between floodplain slope and functional capacity

as water depth increases, obstructions are overtopped and cease to be a source of friction or turbulence, causing the roughness coefficient to decrease.

Manning's roughness coefficient *(n)* is used to quantify this variable. Measure *n* at the depth of flooding indicated by onsite data (e.g., stage recorder) or by hydrologic indicators (i.e., silt lines, water marks, bryophyte - lichen lines, debris lines, etc.). If onsite data or indicators are not present, evaluate *n* at or slightly above ground surface (i.e., within 0.3 m (1 ft)). Once the depth of flooding is determined, measure *n* using one of the following procedures.

(1) Alternative #1 - Use Arcement and Schneider's (1989) method for estimating Manning's roughness coefficient, based on a characterization of the different components that contribute to roughness on floodplains which include: micro- and macrotopographic relief (n_{TOPO}), obstruction (n_{OBS}), and vegetation (n_{VEG}). The following steps are needed to use this method:

   (a) Determine n_{BASE}, the contribution to roughness of the soil surface. Arcement and Schneider (1989) suggest using 0.03, the value for firm soil.

   (b) Using the descriptions in Table 6, assign adjustment values to the roughness components of n_{TOPO}, n_{OBS}, and n_{VEG}.

   (c) Sum the values of the roughness components to determine floodplain roughness. For example, Manning's roughness coefficient $(n) = n_{BASE} + n_{TOPO} + n_{OBS} + n_{VEG}$.

(2) Alternative #2 (not recommended) - Compare the area to be assessed to the photographs of forested floodplains presented in Arcement and Schneider (1989). These photographs illustrate a variety of conditions for which Manning's roughness coefficient has been calculated empirically and can be used in the field to estimate Manning's roughness coefficient for sites that are well stocked with trees.

(3) Report Manning's roughness coefficient as a unitless number.

In western Kentucky reference wetlands, Manning's roughness coefficient ranged from 0.04 to 0.20 (Appendix D). These values were based on setting n_{BASE} to 0.03 and adjustment values for the topographic relief component (n_{TOPO}) that ranged from 0.005-0.01, the obstructions component (n_{OBS}) that ranged from 0.01-0.05, and the vegetation component (n_{VEG}) that ranged from 0.05-0.15.

Based on the range of values at reference standard sites, a variable subindex of 1.0 is assigned to Manning's roughness coefficients between 0.11 and 0.13 (Figure 10). Sites with higher roughness coefficients are also assigned a subindex of 1.0, based on the assumption that the increased roughness does not significantly increase retention time. Lower roughness coefficients were assigned a linearly decreasing subindex down to 0.5 at ≤0.03. This reflects the approximate five-fold increase in flow velocity that occurs as floodplain roughness decreases from 0.11 to 0.03 when holding hydraulic radius and slope constant in Manning's equation.

Table 6
Adjustment Values for Roughness Components Contributing to Manning's Roughness Coefficient (*n*)

Roughness Component	Adjustment to *n* value	Description of Conditions
Topographic relief (n_{TOPO})	0.0	Representative area is flat with essentially no microtopographic relief (i.e., hummocks or holes created by tree fall) or macrotopographic relief (i.e., ridges and swales).
	0.005	Microtopographic relief (i.e., hummocks or holes created by tree fall) or macrotopographic relief (i.e., ridges and swales) cover 5-25% of a representative area.
	0.01	Microtopographic relief (i.e., hummocks or holes created by tree fall) or macrotopographic relief (i.e., ridges and swales) cover 26-50% of a representative area.
	0.02	Microtopographic relief (i.e., hummocks or holes created by tree fall) or macrotopographic relief (i.e., ridges and swales) cover >50% of a representative area.
Obstructions (n_{OBS}) (includes coarse woody debris, stumps, debris deposits, exposed roots)	0.0	No obstructions present
	0.002	Obstructions occupy 1-5% of a representative cross sectional area .
	0.01	Obstructions occupy 6-15% of a representative cross sectional area.
	0.025	Obstructions occupy 16-50% of a representative cross sectional area.
	0.05	Obstructions occupy >50% of a representative cross sectional area.
Vegetation (n_{VEG})	0.0	No vegetation present
	0.005	Representative area covered with herbaceous or woody vegetation where depth of flow exceeds height of vegetation by > 3 times.
	0.015	Representative area covered with herbaceous or woody vegetation where depth of flow exceeds height of vegetation by > 2-3 times.
	0.05	Representative area covered with herbaceous or woody vegetation where depth of flow is at height of vegetation.
	0.1	Representative area fully stocked with trees and with sparse herbaceous or woody understory vegetation.
	0.15	Representative area partially to fully stocked with trees and with dense herbaceous or woody understory vegetation.

Note: Adapted from Arcement and Schneider (1989) and Aldridge and Garrett (1973)

Functional capacity index

The assessment model for calculating the functional capacity index (FCI) is as follows:

$$FCI = \left[\left(V_{FREQ} \times V_{STORE} \right)^{1/2} \times \left(\frac{F_{SLOPE} + V_{ROUGH}}{2} \right) \right]^{1/2} \tag{2}$$

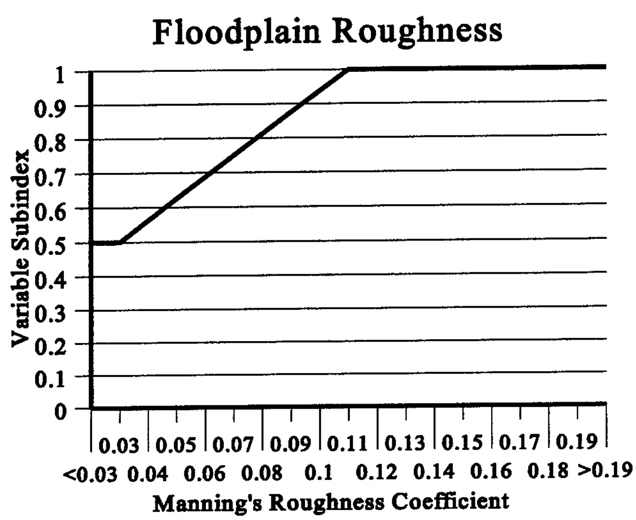


Figure 10. Relationship between floodplain roughness and functional capacity

In the model, the capacity of a riverine wetland to temporarily store surface water depends on three characteristics. In the first part of the model, V_{FREQ} indicates the ability of water to get to the riverine wetland as reflected by recurrence interval. The variable V_{STORE} indicates the volume that is available for storing surface water and reflects whether this volume has been reduced by structures (i.e., levees), fill, or other cultural alterations. The relationship between V_{FREQ} and V_{STORE} is assumed to be partially compensatory. This means that the variables contribute independently and equally to the performance of the function (WRP in preparation, Chapter 4). A geometric mean is used to average the two values. The use of a geometric means that if the subindex of a variable drops to zero, the results from that particular portion of the model will be zero. For example, if the subindex for V_{STORE} drops to zero, the results from the first half of the model will be zero. In this particular model, the FCI will also drop to zero because a geometric mean is used to combine the first and second half of the model. This simply means that as the recurrence interval decreases, or as the width of the floodplain is increasingly constricted by levees or roads, temporary surface water storage is reduced or, in the case of a variable subindex dropping to zero, eliminated. Use of an arithmetic mean to combine V_{FREQ} or V_{STORE} or the first and second part of the equation would require that the subindices for all variables be zero in order for the FCI to equal zero, which is clearly inappropriate in this model.

In the second part of the model, V_{ROUGH} and V_{SLOPE} reflect the ability of the wetland to reduce the velocity of water as it moves through the wetland. These variables are also assumed to be partially compensatory, but in this case they are combined using an arithmetic mean. This makes the model relatively less sensitive to low subindices of V_{ROUGH} and V_{SLOPE} (WRP in preparation, Chapter 4). This is consistent with the assumption that V_{ROUGH} and V_{SLOPE} are less important in determining functional capacity than either V_{FREQ} or V_{STORE}.

Function 2: Maintain Characteristic Subsurface Hydrology

Definition

Maintain Characteristic Subsurface Hydrology is defined as the capacity of a riverine wetland to store and convey subsurface water. Potential sources of subsurface water are direct precipitation, interflow (i.e., unsaturated subsurface flow), groundwater (i.e., saturated subsurface flow), and overbank flooding. A potential independent, quantitative measure for validating the functional index is the cumulative number of days in a year that a characteristic depth to water table is maintained.

Rationale for selecting the function

Maintaining a characteristic subsurface hydrology in riverine wetlands is important for at least three reasons. First, it ensures that the biogeochemical processes and plant and animal communities that depend on subsurface water continue to exist. It also ensures that subsurface contributions to the baseflow and stormflow components of the stream hydrograph, originating in variable source areas (Kirkby 1978, Freeze and Cherry 1979), are maintained. The stream hydrograph has a strong influence on the development and maintenance of habitat structure and biotic diversity of adjacent stream ecosystems (Bovee 1982, Estes and Orsborn 1986, Stanford et al. 1996). Finally, the seasonal fluctuation of the water table that occurs in some riverine wetlands makes soil pore space for belowground storage available during flood events.

Characteristics and processes that influence the function

Because of their unique transitional location, riverine wetlands influence subsurface water as it moves down the hydraulic gradient from upland areas to the stream channel (Figure 11). As water infiltrates and percolates through upland soils, it follows one of several pathways. For example, it may be lost through evapotranspiration or to a deep regional groundwater path (Winter 1976, 1978). Alternatively, subsurface water can move down toward the riverine wetland in an unsaturated zone as interflow or in a saturated zone as

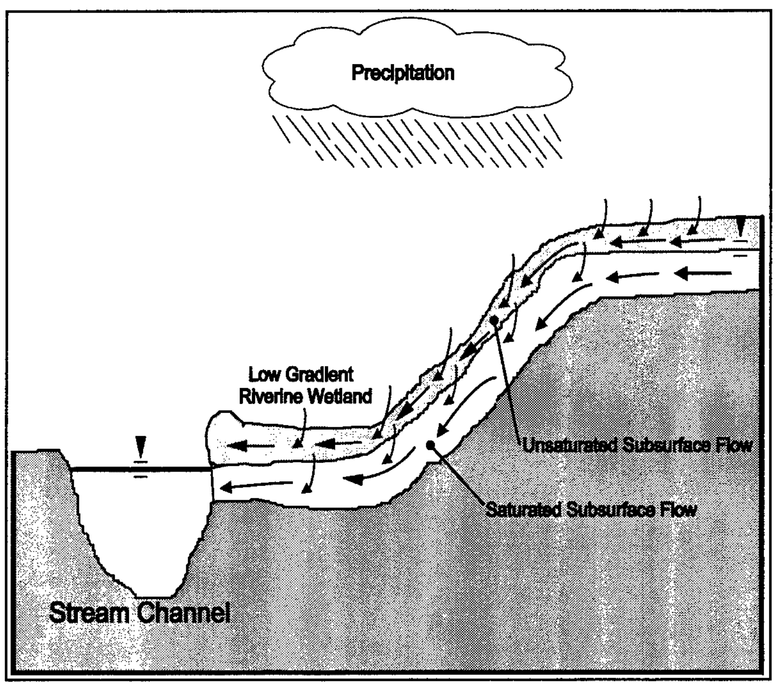


Figure 11. Movement of water down the hydraulic gradient from uplands, through wetlands, and into adjacent stream channels

shallow groundwater (Roulet 1990, O'Brian 1980, Kirkby 1978,). When subsurface water moving as interflow or shallow groundwater reaches the floodplain, it typically encounters a lower slope and substrates with lower hydraulic conductivity and higher porosity (i.e., silty clay and clay soils). These factors combine to reduce the velocity at which subsurface water moves through the riverine wetland to the stream channel. This contributes to the relatively high water table and/or saturated soil conditions often found in riverine wetlands and the ability of riverine wetlands to maintain discharges to the stream channel for long periods.

Assessing the movement of subsurface water through riverine wetlands requires consideration of the factors that influence the movement of water through porous material. These factors are described in Darcy's general equation (Fetter 1988):

$$Q = -K_{SAT}\, A\left(\frac{dh}{dl}\right) \tag{3}$$

where

Q = discharge (volume/time)

K_{SAT} = saturated hydraulic conductivity for the material being observed (distance/time)

A = area through which water is flowing (length^2)

dh/dl = hydraulic gradient or change of head over length of water flow (length/length)

Saturated hydraulic conductivity is determined by the characteristics of the soil and the nature of the fluid moving through the soil (Fetter 1988, Heath 1987). However, since the only fluid of interest here is water, properties of the fluid, such as specific weight and dynamic viscosity, can be considered constant. This leaves the characteristics of the soil as the only factors of concern in determining saturated hydraulic conductivity (Watson and Burnett 1993). Modern county soil surveys provide information on the permeability of soils, which is equivalent to saturated hydraulic conductivity (USDA NRCS 1996).

The area factor (A) in Darcy's general equation, like the properties of the fluid, can be considered constant for the purposes of rapidly assessing subsurface hydrology. The final factor in Darcy's general equation, hydraulic gradient, can be thought of as the force that moves water through the soil. Increasing the hydraulic gradient will increase discharge in the same type of soil. However, soils with different hydraulic conductivities that are subjected to the same hydraulic gradient will transmit water at different rates. For example, water will move through a sandy soil faster than through a clay soil under the same hydraulic gradient because the sandy soil has a higher hydraulic conductivity. In the context of rapid assessment, the slope of the water table from uplands to the stream channel represents the hydraulic gradient in Darcy's general equation.

There are a variety of activities that have the potential to alter subsurface hydrology in riverine wetlands. For example, agricultural activity, silvicultural activity, placement of fill, or the compaction of soil with heavy equipment during construction projects or surface mining can alter soil permeability and porosity. Other alterations, such as construction of ditches, installation of

drainage tile, and channelization, can change the slope of the water table and hence the hydraulic gradient in riverine wetlands.

Description of model variables

Subsurface water velocity ($V_{SOILPERM}$). This variable represents the rate at which subsurface water moves down the hydraulic gradient through riverine wetland soils and into the stream channel. When the velocity of subsurface water is high, subsurface water moves through the riverine wetland relatively quickly, and the period of time that subsurface water discharges to the adjacent stream is short. When velocity is slow, subsurface water moves through more slowly, and the period of time that subsurface water discharges to the adjacent stream is longer.

Soil permeability is used to quantify this variable. Measure it with the following procedure.

(1) Determine if soils in the area being assessed have been altered by agricultural activity, silvicultural activity, placement of fill, use of heavy equipment in construction projects or surface mining, or any other activities with the potential to alter effective soil permeability.

(2) If soils have been altered, select one of the two following alternatives, otherwise skip to Step 3.

(a) Assign a value to soil permeability based on a representative number of field measurements of soil permeability. The number of measurements will depend on how variable and spatially heterogeneous the effects of the alteration are on soil properties. Appendix C provides a procedure for measuring soil permeability in the field using a "pumping test" in which water is pumped quickly from a groundwater well and the rate at which the water level recovers is measured (Freeze and Cherry 1979).

(b) Assign a variable subindex based on the category of alteration that has occurred at the site (Table 7). (Note: in this particular situation, no value is assigned to soil permeability, rather a variable subindex is assigned directly.)

(3) If the soils have not been altered, select one of the two following alternatives.

(a) Alternative 1: Assign a value to soil permeability based on a representative number of field measures of soil permeability. The number of field measures will depend on how variable and spatially heterogeneous the onsite soils are. Appendix C provides a procedure for measuring soil permeability in the field using a "pumping test" in which water is pumped quickly from a groundwater well and the rate at which the water level recovers is measured (Freeze and Cherry 1979).

(b) Alternative 2: Assign a value to soil permeability by calculating the weighted average of median soil permeability to a depth of 50.8 cm (20 in.). Information for the soil series that occur in western Kentucky riverine wetlands is in Table 8. Calculate the weighted average of median soil permeability by averaging the median soil permeability values to a depth of 50.8 cm (20 in.). For example, in

Table 7
Soil Permeability Values (in./hr) for Silvicultural, Agricultural, and Other Alterations

Alteration Category	"Typical" Soil Permeability After Alteration	Average Depth of Alteration Effects	Variable Subindex
Silviculture: normal activities compact surface layers and reduce permeability to a depth of about 15.2 cm (6 in.) (Aust 1994)	highly variable and spatially heterogeneous	top 15.2 cm (6 in.) of soil profile	0.7
Agricultural tillage: some surface compaction occurs as well as generally decreasing the average size of pore spaces which decreases the ability of water to move through the soil to depth of about 15.2 cm (6 in.) (Drees et al. 1994).	highly variable and spatially heterogeneous	top 15.2 cm (6 in.) of soil profile	0.7
Construction activities/surface mining: compaction resulting from large equipment over the soil surface, cover of soil surface with pavement or fill material, or excavation and subsequent replacement of heterogeneous materials	highly variable and spatially heterogeneous	entire soil profile	0.1

Table 8
Soil Permeability at Different Depths for Soil Series in Western Kentucky

Soil Series	Depth, cm (in.)	Range of Soil Permeability, cm (in.) per hr	Weighted Average Soil Permeability in top 50.8 cm (20 in.), cm (in.) per hr
Belknap	0-50.8 (0-20)	1.5-5.1 (0.6-2.0)	3.3 (1.3)
Bonnie	0-50.8 (0-20)	0.5-1.5 (0.2-0.6)	1.0 (0.4)
Karnak	0-12.7/>12.7-50.8 (0-5 / >5-20)	0.5-1.5/<0.5 (0.2-0.6 / <0.2)	0.64 (0.25)
McGary	0-20.3/>20.3-50.8 (0-8 / >8-20)	1.5-5.1/<0.5 (0.6-2.0 / <0.2)	1.63 (0.64)
Melvin	0-50.8 (0-20)	1.5-5.1 (0.6-2.0)	3.3 (1.3)
Newark	0-50.8 (0-20)	1.5-5.1 (0.6-2.0)	3.3 (1.3)
Nolin	0-50.8 (0-20)	1.5-5.1 (0.6-2.0)	3.3 (1.3)
Steff	0-50.8 (0-20)	1.5-5.1 (0.6-2.0)	3.3 (1.3)
Stendal	0-50.8 (0-20)	1.5-5.1 (0.6-2.0)	3.3 (1.3)
Waverly	0-50.8 (0-20)	1.5-5.1 (0.6-2.0)	3.3 (1.3)
Zipp	0-25.4/>25.4-50.8 (0-10 / >10-20)	0.5-5.1/0.2-0.5 (0.2-2.0/0.06-0.2)	1.6 (0.62)

Table 8 the Karnak series has a median soil permeability value from a depth of 0-12.7 cm (0-5 in.) of 0.4 and a median soil permeability value from a depth of 15.2-50.8 cm (6-20 in.) of 0.2. Thus, the weighted average of the median soil permeability for the top 50.8 cm (20 in.) is $((5 \times 0.4) + (15 \times 0.2)) / 20 = 0.25$. These weighted averages have been calculated and are found in Table 8 for several common west Kentucky hydric soils.

(4) Report soil permeability in inches/hour.

In western Kentucky reference wetlands, soil permeability ranged from 0.0 to 5.0 cm/hr (0.0 to 2.0 in./hr) (Appendix D) based on soil survey data. This range corresponds to the NRCS permeability classes of very slow to moderate (USDA NRCS 1996). Based on the range of soil permeability at reference standard sites, a variable subindex of 1.0 was assigned to unaltered sites with a soil permeability <5.0 cm/hr (<2.0 in./hr) (Figure 12). As soil permeability increases, a decreasing subindex is assigned down to 0.1 at 15.2 cm/hr (6 in./hr) based on the assumption that the increase in soil permeability is linearly related to the capacity of a riverine wetland to maintain characteristic subsurface hydrology. A soil permeability >6.0 is assigned a subindex of 0.1 based on the assumption that all soils, regardless of their permeability, reduce the velocity of water to some degree as it moves through the soil.

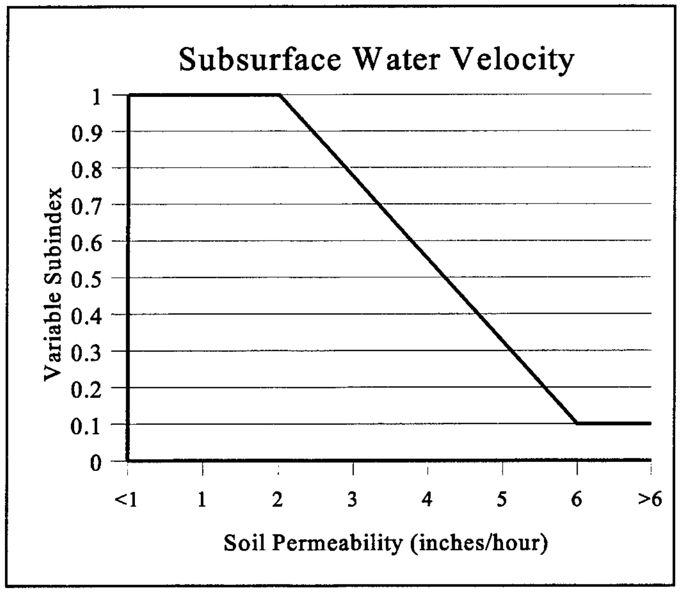


Figure 12. Relationship between soil permeability and functional capacity

Sites altered by agricultural (e.g., plowing or cultivation) or silvicultural activities (e.g., cutting, shearing, or skidding) were assigned a variable subindex of 0.7 (Table 7). This is based on data from Aust (1994) and Drees et al. (1994) which indicate that, as a result of these activities, soil properties are generally altered in the top 15.2 cm (6 in.) of the soil profile. This means that soil permeability in the lower 35.6 cm (14 in.), or 70 percent of the 50.8 cm (20 in.) soil profile, is unaltered. Thus, a subindex of 0.7 is assigned. Sites altered by construction activities, surface mining, or other activities that affect the entire soil profile are assigned a subindex of 0.1 based on the fact that all soils, regardless of their permeability, reduce the velocity of water to some degree as it moves through the soil.

Water table slope *($V_{WTSLOPE}$)*. This variable represents the change in elevation of the water table moving from the upland areas adjacent to the riverine wetland to the nearest stream channel along a line perpendicular to the center line of the floodplain. It is assumed that, in unaltered riverine wetlands, the slope of the water table mimics the floodplain surface (Figure 13). The slope of the water table and, consequently, the velocity at which subsurface water moves down the hydraulic gradient can be modified by alterations such as ditching or tiling (Figure 13a). Channelization or dredging in the adjacent stream channel can also increase the water table slope and would be calculated in the same manner as above, with the channelized or dredged stream being treated in the same manner as a ditch (Figure 13b).

The percentage of the assessment area with an altered water table slope is used to quantify this variable. Measure it with the following procedure.

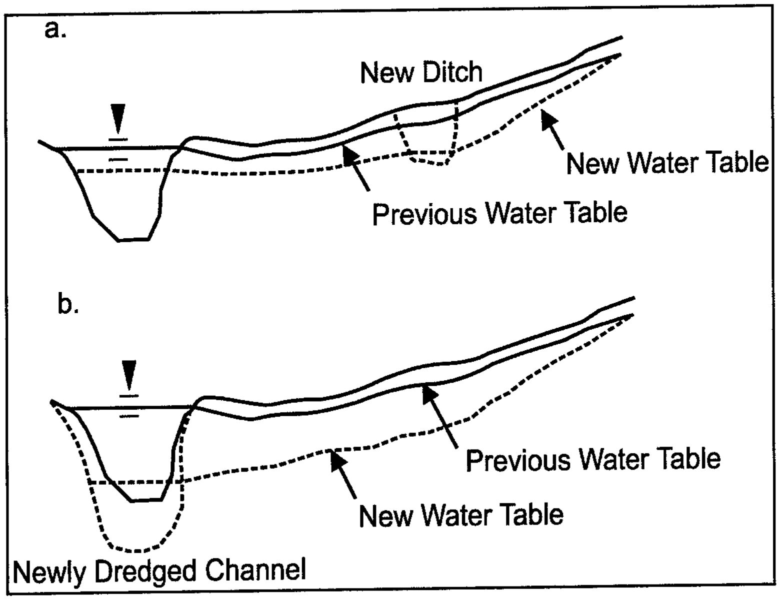


Figure 13. Change in water table slope after ditching or channel dredging

(1) Determine if the slope of the water table has been altered by ditching, tiling, dredging, channelization, or other activities with the potential to modify the water table slope.

(2) If the slope of the water table has not been altered, the percent of the area altered is 0.0.

(3) If the water table slope has been altered in any portion of the assessment area, determine the soil type and the "depth of the alteration." For example, if a ditch has been dug, the depth of the alteration is the depth of the ditch measured from the original ground surface. If a stream channel has been dredged, the depth of the alteration is the difference between the old and new channel depth.

(4) Use Table 9 to determine the lateral distance that will be affected by the alteration. The lateral distances listed in Table 9 are for one side of the ditch only. If the area being assessed extends to both sides of the ditch or channel alteration, then the lateral effect distances require doubling. For example, if the soil is in the Belknap series and the depth of the alteration is 1.5 m (5 ft), the lateral ditch effect is 166 m (544 ft). If the area being assessed extends on both sides of the ditch, the lateral effect is for 332 m (1088 ft). The procedures used to calculate the values in Table 9 are based on the Ellipse Equation (USDA NRCS 1977) described in Appendix C.

(5) Using the lateral distance of the effect and the length of the alteration, estimate the size of the area that is affected by the alteration. For example, if the lateral effect of the ditch is 166 m (544 ft) and the ditch is 15.24 m (50 ft) long, the area affected is 544 × 50 = 27,200 ft^2 (0.62 acres (0.25 ha)).

(6) Calculate the ratio of the size of all areas within the area being assessed that are affected by an alteration to the water table slope to the size of the entire assessment area. For example, if the area inside the assessment area affected by the alteration is 0.25 ha (0.62 acres), and the entire assessment area is 4 ha (10 acres) the ratio is 0.25/4 = 0.062 (0.62/10 = 0.062).

(7) Multiply the ratio by 100 to obtain the percentage of the area being assessed with an altered water table slope.

Table 9 Lateral Effect of Ditches for Selected Soil Series in Western Kentucky								
	Depth of Ditch or Change in Depth of Channel, m (ft)							
Soil Series	3	4	5	6	7	8	9	10
Belknap	91 (300)	132 (434)	166 (544)	196 (642)	223 (732)	249 (818)	274 (900)	299 (980)
Bonnie	72 (235)	104 (341)	130 (427)	153 (503)	175 (574)	196 (642)	215 (706)	234 (769)
Karnak	48 (156)	69 (225)	86 (282)	101 (333)	116 (380)	129 (424)	142 (467)	155 (509)
McGary	87 (284)	125 (410)	157 (514)	185 (606)	211 (692)	236 (773)	259 (851)	282 (926)
Melvin	129 (424)	187 (614)	234 (769)	277 (908)	316 (1036)	353 (1157)	388 (1273)	422 (1386)
Newark	129 (424)	187 (614)	234 (769)	277 (908)	316 (1036)	353 (1157)	388 (1273)	422 (1386)
Nolin	129 (424)	187 (614)	234 (769)	277 (908)	316 (1036)	353 (1157)	388 (1273)	422 (1386)
Steff	129 (424)	187 (614)	234 (769)	277 (908)	316 (1036)	353 (1157)	388 (1273)	422 (1386)
Stendal	129 (424)	187 (614)	234 (769)	277 (908)	316 (1036)	353 (1157)	388 (1273)	422 (1386)
Waverly	129 (424)	187 (614)	234 (769)	277 (908)	316 (1036)	353 (1157)	388 (1273)	422 (1386)
Zipp	72 (236)	104 (341)	130 (427)	154 (504)	175 (575)	196 (643)	215 (707)	235 (770)

(8) Report the percentage of the area being assessed with an altered water table slope.

In western Kentucky reference wetlands, the percentage of the area being assessed with an altered water table slope ranged from zero to 100 (Appendix D). Based on the range of values from reference standard sites a variable subindex of 1.0 is assigned when the percent altered area is zero (Figure 14). As the percentage of area increases, a linearly decreasing subindex is assigned based on the assumption that the percentage of altered area is inversely related to the capacity of the riverine wetland to maintain a characteristic subsurface hydrology.

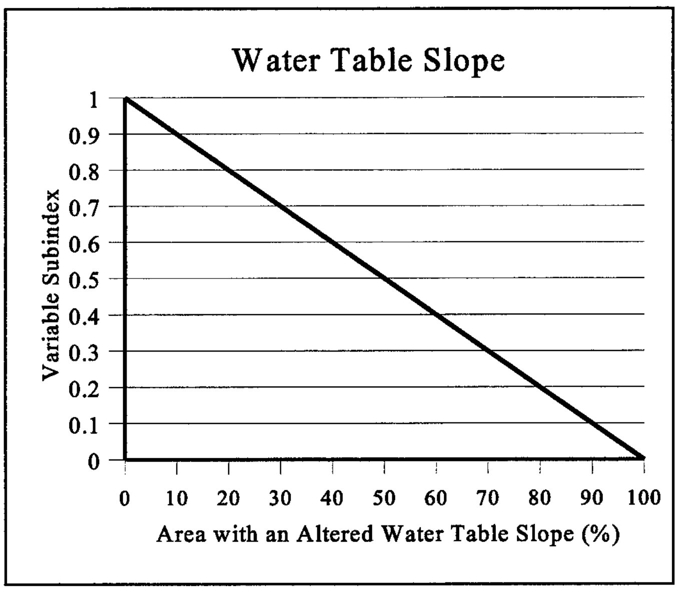


Figure 14. Relationship between water table slope and functional capacity

Subsurface storage volume (***V_{PORE}***). This variable represents the volume of space available below the ground surface for storing water after adjusting for antecedent moisture conditions (Dunne and Leopold 1978). Like subsurface water velocity, this variable is difficult to assess rapidly. The only types of change that can be detected in a rapid assessment context are relatively gross changes in subsurface storage volume that result from activities such as agricultural, silvicultural, construction, or surface mining that significantly alter or replace the soil profile.

Percent effective soil porosity is used to quantify this variable. Measure it with the following procedure:

(1) Determine if soils in the area being assessed have been altered by agricultural activity, silvicultural activity, placement of fill, use of heavy equipment in construction projects or surface mining, or any other activities with the potential to alter effective soil permeability.

(2) If soils have been altered:

   (a) Assign a value to soil permeability based on a representative number of field measures of soil bulk density. The number of field measures will depend on how variable and spatially heterogeneous the effects of the alteration are on soil properties. Appendix C provides a procedure for using measurements of bulk density to determine effective soil porosity.

   (b) Assign a variable subindex based on the category of alteration that has occurred at the site shown in Table 10. (Note: in this particular situation, no value is assigned to the metric, rather a variable subindex is assigned directly.)

Table 10
Variable Subindices for Soils Altered by Silvicultural, Agricultural, and Construction/Mining Activities

Alteration Category	"Typical" Effective Soil Porosity After Alteration	Average Depth of Alteration Effects	Variable Subindex
Silviculture: normal activities compact surface layers and reduce permeability to a depth of about 15.2 cm (6 in.) (Aust 1994)	highly variable and spatially heterogeneous	top 15.2 cm (6 in.) of soil profile	0.7
Agricultural tillage: some surface compaction occurs as well as generally decreasing the average size of pore spaces which decreases the ability of water to move through the soil to a depth of about 15.2 cm (6 in.) (Drees et al. 1994).	highly variable and spatially heterogeneous	top 15.2 cm (6 in.) of soil profile	0.7
Construction activities/surface mining: compaction resulting from large equipment over the soil surface, cover of soil surface with pavement or fill material, or excavation and subsequent replacement of heterogeneous materials	highly variable and spatially heterogeneous	entire soil profile	0.1

(3) If the soils have not been altered, quantify percent effective soil porosity using one of the following alternatives.

   (a) Alternative 1: Collect a representative number of field measures of bulk density and use the procedure outlined in Appendix C to determine percent effective soil porosity. The number of field measures of bulk density will depend on how variable and spatially heterogeneous the effects of the alteration are on soil properties.

(b) Alternative 2: Use the percent effective soil porosity values for particular soil series provided in Table 11. The procedures used to calculate these values in this table are provided in Appendix C.

(4) Report subsurface storage volume as percent effective soil porosity.

Table 11
Calculation of Effective Porosity for 11 Hydric Soils in Western Kentucky[1]

Soil Series	Median Bulk Density, g/cm^3	Total Porosity, %	Residual Water Content, %	Effective Soil Porosity, %	Soil Texture
Belknap	1.45	45	1.5	43.5	SiL
Bonnie	1.4	47	4.0	43.0	SiCL
Karnak	1.3	51	5.6	45.4	SiC
McGary	1.5	44	4.0	40.0	SiCL
Melvin	1.4	48	1.5	46.5	SiL
Newark	1.3	51	2.8	48.2	SiL, SiCL
Nolin	1.34	49	2.8	46.2	SiL, SiCL
Steff	1.4	47	2.8	44.2	SiL,SiCL
Stendal	1.47	45	1.5	43.5	SiL
Waverly	1.45	45	1.5	43.5	Si,SiL
Zipp	1.47	45	7.5	37.5	SiC, C

[1] Appendix C presents specific procedures.

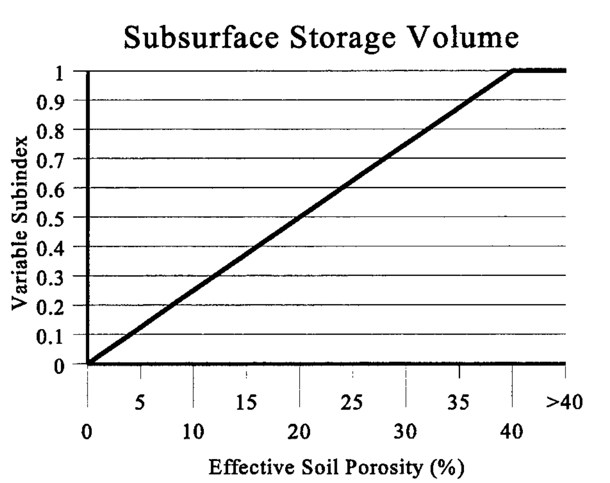


Figure 15. Relationship between effective soil porosity and functional capacity

In western Kentucky reference wetlands, effective soil porosity ranged from 26 to 47 percent (Appendix D). Based on the range of values at reference standard sites, a variable subindex of 1.0 was assigned to effective soil porosity ≥40 percent (Figure 15). As soil porosity decreases, a linearly decreasing subindex down to 0.0 was assigned. This is based on the assumption that, as soil porosity decreases, the volume available for storing water below the surface also decreases to zero. Sites altered by agricultural (e.g., plowing or cultivation) or silvicultural activities (e.g., cutting, shearing, or skidding) were assigned a variable subindex of 0.7 (Table 10). This is based on data

from Aust (1994) and Drees et al. (1994) which indicates that, as a result of these activities, soil properties are generally altered in the top 15.2 cm (6 in.) of the soil profile. This means that effective soil porosity in the lower 35.6 cm (14 in.), or 70 percent of the 50.8-cm (20-in.) soil profile, is unaltered. Thus, a subindex of 0.7 is assigned. Sites altered by construction activities, surface mining, or other activities that affect the entire soil profile are assigned a subindex of 0.1 based on the fact that all soils, regardless of their effective soil porosity, provide some storage volume.

Water table fluctuation (V_{WTF}). This variable represents the upward and downward fluctuation of the water table that occurs throughout the year in riverine wetlands as a result of precipitation, evapotranspiration, groundwater movement, and flood events. As the water table drops, soil pore space becomes available for storing water below the surface. When the water table is at its highest level (typically in winter and early spring), the wetland soil is saturated. These types of fluctuations occur, to some extent, in all riverine wetland soils in western Kentucky (Quinones, York, and Plebuch 1983) and represent the soil wetting and drying cycle which contributes to typical soil antecedent moisture conditions.

Presence or absence of a fluctuating water table is used to categorize this variable. Assign a category with the following procedure.

(1) Determine whether the water table at the site fluctuates by using the following criteria (in order of decreasing accuracy and preference):

  (a) groundwater monitoring well data

  (b) redoximorphic features such as oxidized rhizospheres, reaction to *a,a'* dipyridyl, or the presence of a reduced soil matrix (Verpraskas 1994; Hurt, Whited, and Pringle 1996), remembering that some redoximorphic features reflect that a soil has been anaerobic at some time in the past but do not necessarily reflect current conditions

  (c) the presence of a fluctuating water table according to the Soil and Water Features Table in modern County Soil Surveys. In situations where the fluctuation of the water table has been altered as a result of raising the land surface above the water table through the placement of fill, the installation of drainage ditches, or drawdown by water supply wells, the information in the soil survey is no longer useful. Under these circumstances, the use of well data or redoximorphic features that indicate current conditions may be the only way to obtain the necessary information.

(2) Report water table fluctuations as present or absent.

In western Kentucky reference wetlands, the evidence of a fluctuating water table was present and absent (Appendix D). Based on the range of values from reference standard sites, a variable subindex of 1.0 is assigned when evidence of a fluctuating water table is present (Figure 16). A subindex of zero is assigned when evidence of a fluctuating water table is absent. This is based on the assumption that if a fluctuating water table is absent (i.e., removed by the placement of fill, the installation of drainage ditches, drawdown by water supply wells, or by permanent inundation) then the antecedent moisture conditions have been altered, and the subsequent movement of subsurface water has been affected.

Functional capacity index

The assessment model for calculating the functional capacity index is as follows:

$$FCI = \left[\frac{\left(V_{SOILPERM} \times V_{WTSLOPE}\right)^{1/2} + \left(\frac{V_{PORE} + V_{WTF}}{2} \right)}{2} \right] \quad (4)$$

In the model, the capacity of the riverine wetland to maintain subsurface hydrology focuses on two characteristics. The first is the effect riverine wetlands have on subsurface water as it moves from adjacent uplands to the stream channel. The second is the ability of the riverine wetland to maintain characteristic fluctuations in the water table that set up the temporal shift from saturated to unsaturated soil pore spaces necessary for storing subsurface water.

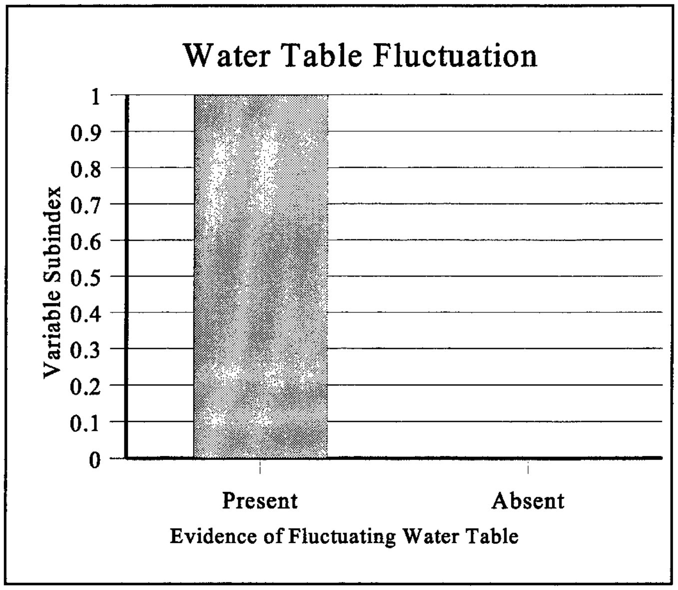


Figure 16. Relationship between fluctuating water table and functional capacity

The first part of the model estimates the velocity at which subsurface water moves from the upland through the riverine wetland to the stream channel. As discussed above, this is based on Darcy's general equation, with $V_{SOILPERM}$ representing hydraulic conductivity and $V_{WTSLOPE}$ representing hydraulic gradient. In the equation, $V_{SOILPERM}$ and $V_{WTSLOPE}$ are partially compensatory, based on the assumption that they contribute equally and independently to the performance of the function (WRP in preparation, Chapter 4). The use of a geometric mean to combine these variables is consistent with the relationship defined in Darcy's general equation.

The second part of the model estimates volume for storing water below the surface of the ground and the likelihood that the water will fluctuate and provide pore space necessary for storing subsurface water. In riverine wetlands, this depends largely on maintaining characteristic seasonal fluctuations of the water table and soil porosity. V_{WTD} represents the fluctuation of the water table, and V_{PORE} represents soil porosity. These two variables are partially compensatory because they are assumed to contribute equally and independently to the performance of the function. The variables are combined using an arithmetic mean to reduce the influence of either variable on the resulting index (WRP in preparation, Chapter 4).

The relationship between the two parts of the model is also partially compensatory because they are believed to contribute equally and independently to the performance of the function. An arithmetic mean is used to reduce the influence of relatively low values from either part of the model on the resulting FCI.

Function 3: Cycle Nutrients

Definition

Cycle Nutrients is defined as the ability of the riverine wetland to convert nutrients from inorganic forms to organic forms and back through a variety of biogeochemical processes such as photosynthesis and microbial decomposition. Potential independent, quantitative measures for validating the functional index include net annual primary productivity (gm/m^2), annual litter fall (gm/m^2), or standing stock of living and/or dead biomass (gm/m^2).

Rationale for selecting the function

The cycling of nutrients is a fundamental function that helps to maintain an adequate pool of nutrients throughout the various compartments of an ecosystem (Ovington 1965, Pomeroy 1970, Ricklefs 1990). For example, an adequate supply of nutrients in the soil profile supports primary production which makes it possible for the plant community to develop and be maintained (Bormann and Likens 1970, Whittaker 1975, Perry 1994). The plant community, in turn, provides a pool of nutrients and source of energy for secondary production and also provides the habitat structure necessary to maintain the animal community (Fredrickson 1978, Crow and MacDonald 1978, Wharton et al. 1981). Plant and animal communities serve as the source of detritus which provides nutrients and energy necessary to maintain a characteristic community of decomposers to break down organic material into simpler elements and compounds that can then reenter the nutrient cycle (Reiners 1972; Dickinson and Pugh 1974; Pugh and Dickinson 1974; Schlesinger 1977; Singh and Gupta 1977; Hayes 1979; Harmon, Franklin, and Swanson 1986; Vogt, Grier, and Vogt 1986).

Characteristics and processes that influence the function

In riverine wetlands, nutrients are stored within, and cycled between, four major compartments: (a) the soil, (b) primary producers such as vascular and nonvascular plants, (c) consumers such as animals, fungi, and bacteria, and (d) dead organic matter, such as leaf litter or woody debris, referred to as detritus. The transformation of nutrients within each compartment and the flow of nutrients between compartments are mediated by a complex variety of biogeochemical processes. For example, plant roots take up nutrients from the soil and detritus and incorporate them into the organic matter in plant tissues. Nutrients incorporated into herbaceous or deciduous parts of plants will turn over more rapidly than those incorporated into the woody parts of plants. However, ultimately, all plant tissues are either consumed (~10 percent) or die and fall to the ground where they are decomposed by fungi and microoganisms and mineralized to again become available for uptake by plants.

Many of the processes involved in nutrient cycling, such as primary production and decomposition, have been studied extensively in wetlands (Brinson, Lugo, and Brown 1981). In forested riverine wetlands of the Southeast specifically, there is a rich literature on the standing stock, accumulation, and turnover of aboveground biomass in successional and mature stages (Brinson 1990). For example, the annual production of leaves is well documented through litterfall studies (Conner and Day 1976, Day 1979, Mulholland 1981, Elder and Cairns 1982, Brown and

Peterson 1983, Conner and Day 1992). Until recently, less attention has been paid to woody (Harmon, Franklin, and Swanson 1986; Symbula and Day 1988) and below-ground components (Raich and Nadelhoffer 1989, Nadelhoffer and Raich 1992) of these systems.

The ideal approach for assessing nutrient cycling would be to measure the rate at which nutrients are transformed and transferred between compartments over the period of a year (Kuenzler et al. 1980; Brinson, Bradshaw, and Kane 1984; Harmon, Franklin, and Swanson 1986). However, the time and effort required to make these measurements are well beyond a rapid assessment procedure. The alternative is to estimate the standing stocks of living and dead biomass in each of the four compartments and assume that nutrient cycling is taking place at a characteristic level if the biomass in each compartment is similar to that in reference standard wetlands.

Description of model variables

Tree biomass (V_{TBA}). This variable represents the total mass of organic material per unit area in the trees that occupy the stratum in riverine forests. Trees are defined as woody stems ≥6 m in height and ≥10 cm in diameter at breast height (dbh) which is 1.4 m above the ground (Bonham 1989). Tree biomass is correlated with forest maturity (Brower and Zar 1984) and, in the context of this function, serves as an indication that trees are present, taking up nutrients, and producing biomass.

Tree basal area, a common measure of abundance and dominance in forest ecology that has been shown to be proportional to tree biomass (Whittaker 1975, Whittaker et al. 1974, Spurr and Barnes 1980, Tritton and Hornbeck 1982, Bonham 1989) is used to quantify this variable. Measure it with the following procedure.

(1) Measure the dbh in centimeters of all trees in a circular 0.04-ha sampling unit (Pielou 1984), hereafter called a plot.

(2) Convert each of the diameter measurements to area, sum them, and convert to square meters. For example, if 3 trees with diameters of 20 cm, 35 cm, and 22 cm were present in the plot, the conversion to square meters would be made as follows. Remembering that the diameter of a circle (D) can be converted to area (A) using the relationship $A = 1/4\pi D^2$, it follows that $1/4\pi 20^2 = 314$ cm^2, $1/4\pi 35^2 = 962$ cm^2, $1/4\pi 22^2 = 380$ cm^2. Summing these values gives $314 + 962 + 380 = 1656$ cm^2 and converting to square meters by multiplying by 0.0001 gives 1656 cm^2 $\times$ 0.0001 = 0.17 m^2. Not many trees in that plot!

(3) If multiple 0.04-ha plots are sampled, average the results from all plots.

(4) Convert the results to a per hectare basis by multiplying by 25, since there are 25 0.04-ha plots in a hectare. For example, if the average value from all the sampled plots is 0.17 m^2, then 0.17 m^2 $\times$ 25 = 4.3 m^2/ha. A pretty sparse "forest"!

(5) Report tree basal area in square meters per hectare.

The number of 0.04-ha plots required to adequately characterize the area being assessed will depend on its size and heterogeneity. Chapter 5, Assessment Protocol, provides guidance for

determining the number and layout of sample points and sampling units. Other plot-based or plotless methods for measuring tree basal area have been developed and may provide results that are similar to those described above (Lindsey, Barton, and Miles 1958; Suwong, Frayer, and Mogren 1971; Cox 1980, Hays, Summers, and Seitz 1981; Avery and Burkhart 1983; Green 1992).

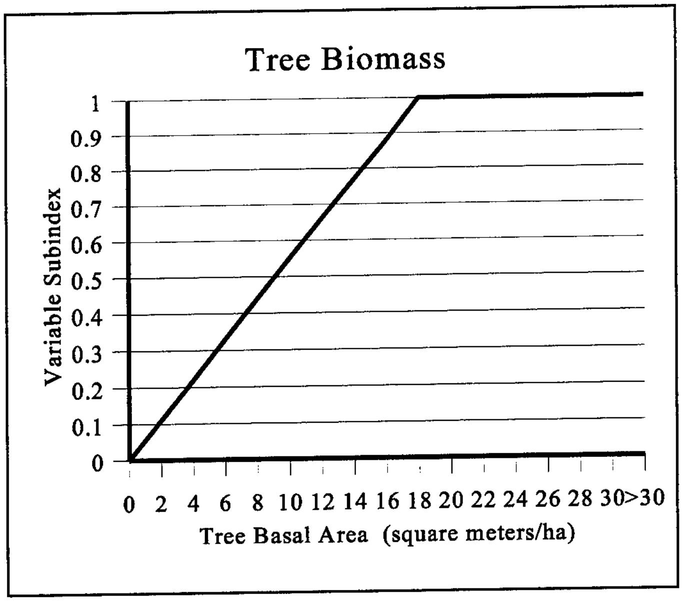


Figure 17. Relationship between tree basal area and functional capacity

In western Kentucky reference wetlands, tree basal area ranged from 0 to 28 m^2/ha (Appendix D). Based on the data from reference standard sites supporting mature, fully stocked forests, a variable subindex of 1.0 is assigned when tree basal area is ≥ 18 m^2/ha (Figure 17). At reference sites in the middle to early stages of succession, or cleared for agriculture, tree basal area decreases, and a linearly decreasing subindex down to zero at zero tree basal area is assigned. This is based on the assumption that the relationship between tree basal area and the capacity of the riverine wetland to cycle nutrients is linear. This assumption could be validated using the data from a variety of low gradient, riverine wetlands in the Southeast summarized by Brinson (1990), Christensen (1991), Sharitz and Mitsch (1993), and Messina and Conner (1997) or by the independent, quantitative measures of function identified above.

Understory vegetation biomass (V_{SSD}). This variable represents the total mass of organic material per unit area in the understory stratum of riverine forests. Understory vegetation is defined as woody stems (e.g., shrubs, saplings, and understory trees) >1 m in height and <10 cm dbh. In the context of this function, this variable serves as an indication that understory vegetation is present, taking up nutrients, and producing biomass.

Stem density in stems per hectare is used to quantify this variable. Measure it with the following procedure.

(1) Count the stems of understory vegetation in either a 0.04-ha plot or each of two 0.004-ha sampling units, hereafter called subplots, located in representative portions of each quadrant of the 0.04-ha plot. Sample using two 0.004-ha subplots if the stand is in an early stage of succession and a high density of stems makes sampling 0.04-ha plots impractical.

(2) If 0.004-ha subplots are used, average the results and multiply by 10 to obtain the value for each 0.04-ha plot.

(3) If multiple 0.04-ha plots are sampled, average the results from all 0.04-ha plots.

(4) Convert the results to a per hectare basis by multiplying by 25. For example, if the average of the 0.04-ha plots is 23 stems, then 23 × 25 = 575 stems/ha.

(5) Report shrub and sapling density as stems per hectare.

The number of 0.04-ha plots required to adequately characterize the area being assessed will depend on its size and heterogeneity. Chapter 5, Assessment Protocol, provides guidance for determining the number and layout of sample points and sampling units.

In western Kentucky reference wetlands, understory vegetation stem density ranged from zero to nearly 6,000 stems/ha (Appendix D). Based on data from reference standard sites, a variable subindex of 1.0 is assigned when understory vegetation stem density is between 250 and 500 stems/ha (Figure 18). As understory stem density decreases, a linearly decreasing subindex down to zero is assigned at zero stems/ha. This is based on the assumption that if understory vegetation does not exist, it does not contribute to nutrient cycling. As understory vegetation stem density increases above 500 stems/ha, a linearly decreasing subindex is assigned down to 0.5 at 750 stems/ha. Above 750 stems/ha a subindex of 0.5 is assigned. The rationale for this is that understory stem density commonly exceeds 500 stems/ha during the middle stages of secondary succession (Whittaker 1975). As the forest matures, competition for resources results in a decrease in understory stem density to the levels observed at reference standard sites. The rates at which the subindex increases and decreases and the leveling out at a subindex of 0.5 above 750 stems/ha represent an educated guess of the relationship between understory stem densities and nutrient cycling. These assumptions could be validated using the data from a variety of low gradient, riverine wetlands in the Southeast summarized by Brinson (1990), Christensen (1991), Sharitz and Mitsch (1993), and Messina and Conner (1997) or by the independent, quantitative measures of function identified above.

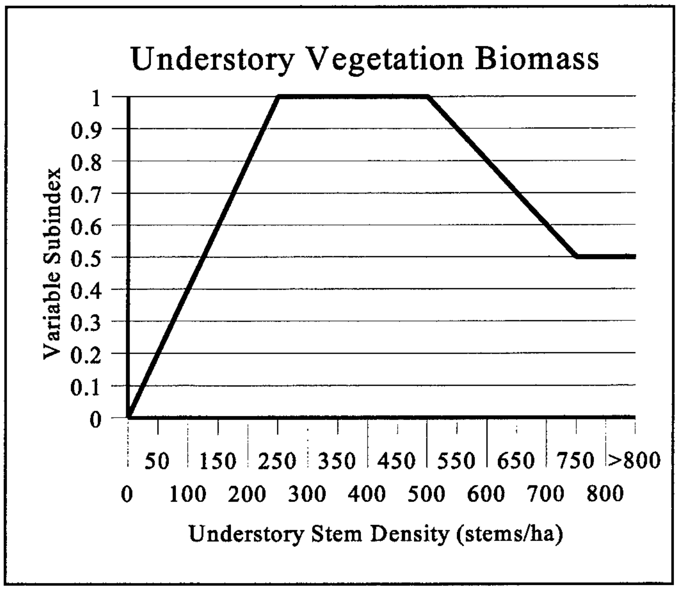


Figure 18. Relationship between understory vegetation stem density and functional capacity

Ground vegetation biomass (V_{GVC}). This variable represents the total mass of organic matter in the woody and herbaceous vegetation near the surface of the ground in riverine forests. Ground vegetation is defined as all herbaceous and woody vegetation <1 m in height. In the context of this function, this variable serves as an indicator that ground vegetation is present, taking up nutrients, and producing biomass.

Percent cover of ground vegetation is used to quantify this variable. Measure it with the following procedure.

(1) Visually estimate the percentage of the ground surface that is covered by ground vegetation by mentally projecting the leaves and stems of ground vegetation to the ground surface in each of four 1-m^2 sampling units, hereafter called subplots, placed in representative portions of each quadrant of a 0.04-ha plot. The number of 0.04-ha plots required to adequately characterize an area will depend on its size and heterogeneity. Chapter 3, Assessment Protocol, provides guidance for determining the number and layout of sample points and sampling units.

(2) Average the values from the four 1-m^2 subplots.

(3) If multiple 0.04-ha plots are sampled, average the results from all the 0.04-ha plots.

(4) Report ground vegetation cover as a percent.

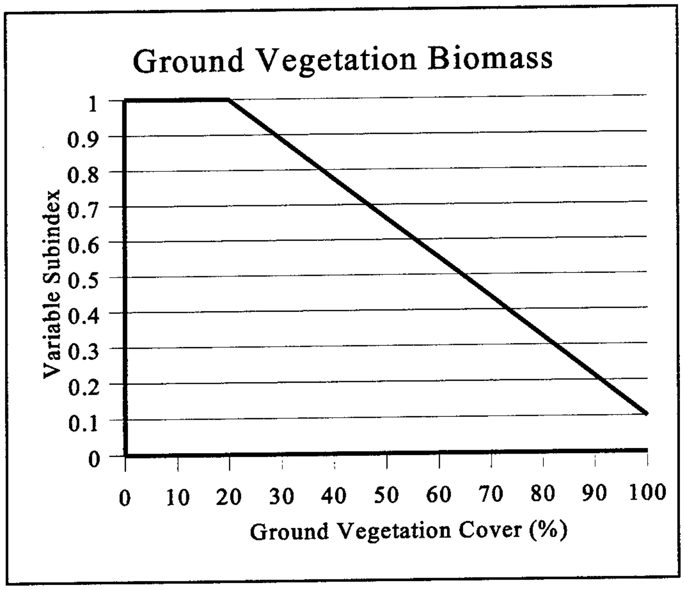


Figure 19. Relationship between ground vegetation cover and functional capacity

In western Kentucky reference wetlands, ground vegetation cover ranged from zero to 100 percent (Appendix D). In reference standard wetlands, the amount of ground vegetation is relatively small due to the low level of light that occurs near the ground surface as a result of light interception by trees, saplings, and shrubs. Based on data from reference standard sites, a variable subindex of 1.0 is assigned to sites with a ground vegetation cover between zero and 20 percent (Figure 19). As ground vegetation cover increases above 20 percent, a linearly decreasing subindex down to 0.1 at 100 percent ground vegetation cover is assigned. This is based on the assumption that the increase in the ground vegetation cover indicates higher levels of light at the ground surface and fewer trees, saplings, and shrubs to maintain a characteristic level of nutrient cycling. The rate at which the subindex decreases, and the selection of 0.1 as the variable subindex endpoint at 100 percent cover, is based on the assumption that the relationship between ground vegetation cover and nutrient cycling is linear and that some overstory and understory vegetation will probably be present and contributing to nutrient cycling even when the percent of ground vegetation cover is high. These assumptions could be validated using the independent, quantitative measures of function defined above.

"O" horizon biomass (V_{OHOR}). This variable represents the total mass of organic matter in the "O" horizon. The "O" horizon is defined as the soil layer dominated by organic material that consists of recognizable or partially decomposed organic matter such as leaves, needles, sticks or

twigs < 0.6 cm in diameter, flowers, fruits, insect frass, moss, or lichens on or near the surface of the ground (USDA SCS 1993). The "O" horizon is synonymous with the term detritus or litter layer used by other disciplines. In the context of this function, this variable serves as an indicator that nutrients in vegetative organic matter are being recycled.

Percent cover of the "O" soil horizon is used to quantify this variable. Measure it with the following procedure.

(1) Visually estimate the percentage of the ground surface that is covered by an "O" horizon in each of four 1-m^2 subplots placed in representative portions of each quadrant of a 0.04-ha plot. The number of 0.04-ha plots required to adequately characterize the area being assessed will depend on its size and heterogeneity. Chapter 5, Assessment Protocol, provides guidance for determining the number and layout of sample points and sampling units.

(2) Average the results from the subplots.

(3) If multiple 0.04-ha plots were sampled, average the results from these plots.

(4) Report "O" horizon cover as a percent.

In western Kentucky reference wetlands, percent "O" horizon cover ranged from zero to 100 percent (Appendix D). Based on data from reference standard sites, a variable subindex of 1.0 is assigned when the "O" soil horizon cover is >60 percent (Figure 20). As "O" horizon cover decreases, a linearly decreasing subindex down to zero at zero percent cover is assigned. The rate at which the subindex decreases, and the selection of zero as the subindex endpoint at 0 percent cover, is based on the assumption that the relationship between "O" soil horizon cover and nutrient cycling is linear and that a decreasing amount of biomass in the tree, sapling, shrub, and ground vegetation strata of the plant community is reflected in lower percent "O" soil horizon cover. When percent "O" soil horizon drops to zero, the contribution of the "O" soil horizon to nutrient cycling has essentially ceased. These assumptions could be validated using the independent, quantitative measures of function defined above.

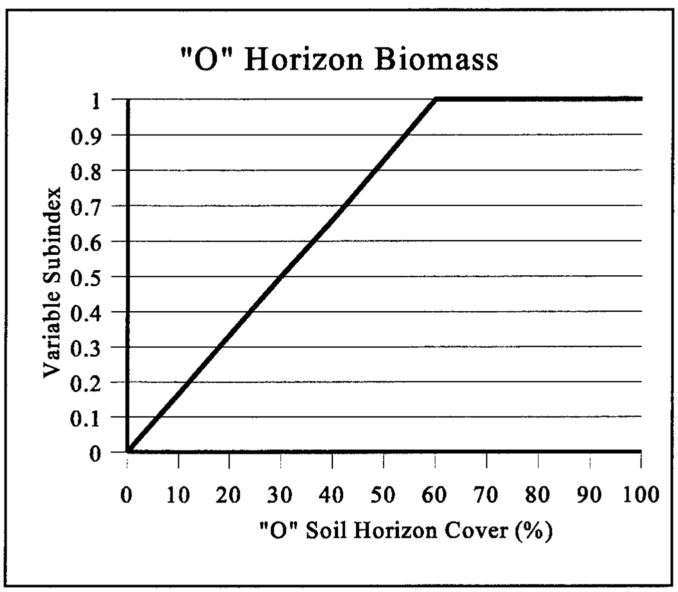


Figure 20. Relationship between "O" soil horizon and functional capacity

"A" Horizon Biomass (V_{AHOR}). This variable represents total mass of organic matter in the "A" horizon. The "A" horizon is defined as a mineral soil horizon that occurs at the ground surface, or below the "O" soil horizon, that consists of an accumulation of unrecognizable

decomposed organic matter mixed with mineral soil (USDA SCS 1993). In addition, for the purposes of this procedure, in order for a soil horizon to be considered an "A" horizon, it must be at least 7.5 cm (3 in.) thick and have a Munsell color value less than or equal to 4. In the context of this function, this variable serves as an indicator that nutrients in vegetative organic matter are being recycled.

Percent cover of the "A" horizon is used to quantify this variable. Measure it with the following procedure.

(1) Estimate the percentage of the mineral soil within the top 15.2 cm (6 in.) of the ground surface that qualifies as an "A" horizon by making a number of soil observations in each of four 1-m^2 subplots placed in representative portions of each quadrant of a 0.04-ha plot. For instance, if, in each subplot, 12 soil plugs are taken and 6 show the presence of a 7.5-cm- (3-in.) thick "A" horizon, the value of "A" horizon cover is $(6/12) \times 100 =$ 50 percent. The number of 0.04-ha plots required to adequately characterize the area being assessed will depend on its size and heterogeneity. Chapter 5, Assessment Protocol, provides guidance for determining the number and layout of sample points and sampling units.

(2) Average the results from the 1-m^2 subplots within each 0.04-ha plot.

(3) If multiple 0.04-ha plots were sampled, average the results from these plots.

(4) Report "A" horizon cover as a percent.

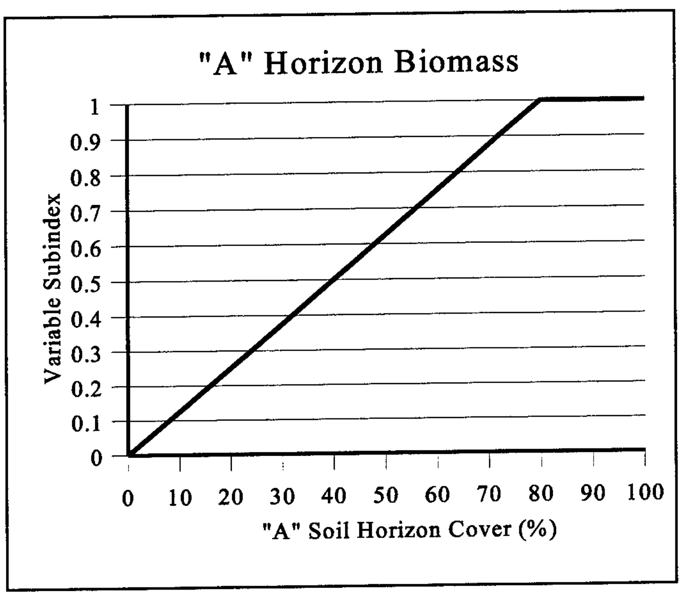


Figure 21. Relationship between "A" soil horizon and functional capacity

In western Kentucky reference wetlands, "A" horizon cover ranged from zero to 100 percent (Appendix D). Based on data from reference standard sites, a variable subindex of 1.0 is assigned when the percent cover of the "A" horizon is ≥80 percent (Figure 21). As the percent cover of the "A" horizon decreases, a linearly decreasing subindex to zero is assigned. This is based on the assumption that the relationship between percent "A" horizon and the capacity to cycle nutrients is linear and reflects the decreasing contribution to "A" horizon biomass by the tree, sapling, shrub, and ground vegetation strata of the plant community. Sites that have been converted to agricultural crops may have low coverage of the "A" horizon due to the oxidation of the organic carbon following tillage (Ismail, Blevins, and Frye 1994).

Woody debris biomass (V_{WD}). This variable represents the total mass of organic matter contained in woody debris on or near the surface of the ground. Woody debris is defined as down and dead woody stems ≥0.25 in. in diameter that are no longer attached to living plants. Despite its relatively slow turnover rate, woody debris is an important component of food webs and nutrient cycles of temperate terrestrial forests (Harmon, Franklin, and Swanson 1986). In the context of this function, this variable serves as an indicator that the nutrients in vegetative organic matter are being recycled.

Volume of woody debris per hectare is used to quantify this variable. Measure it with the following procedure adapted from Brown (1974) and Brown, Oberheu, and Johnston (1982).

(1) Count the number of stems that intersect a vertical plane along a minimum of two transects located randomly and at least partially inside each 0.04-ha plot. Count the number of stems that intersect the vertical in each of three different size classes along the transect distances given below. A 6-ft transect interval is used to count stems ≥0.25 to ≤1.0 in. in diameter; a 12-ft transect interval is used to count stems >1 to ≤3 in. in diameter; and a 50-ft transect is used to count stems >3 in. in diameter.

(2) Convert stem counts for each size class to tons per acre using the following formulas. For stems in the ≥0.25 to ≤1.0 in. and >1 to ≤3 in. size classes, use the formula:

$$Tons/Acre = \frac{(11.64 \times n \times d^2 \times s \times a \times C)}{N \times l} \tag{5}$$

where

n = total number of intersections (i.e., counts) on all transects

d^2 = squared average diameter for each size class

s = specific gravity (Birdsey (1992) suggests a value of 0.58)

a = nonhorizontal angle correction (suggested value: 1.13)

C = slope correction factor (suggested value = 1.0 since slopes in southeastern forested floodplains are negligible)

N = number of transects

l = length of transect in feet

For stems in the >3 in. size class use the following formula:

$$Tons/Acre = \frac{(11.64 \times \Sigma\, d^2 \times s \times a \times C)}{N \times l} \tag{6}$$

where

n = total number of intersections (i.e., counts) on all transects

Σd^2 = the sum of the squared diameters of each intersecting stem

s = specific gravity (Birdsey (1992) suggests a value of 0.58)

a = nonhorizontal angle correction (suggested value: 1.13)

C = slope correction factor (suggested valued: 1.0 since slopes in south-eastern forested floodplains are negligible)

N = number of transects

l = length of transect in feet

When inventorying large areas with many different tree species, it is practical to use composite values and approximations for diameters, specific gravities, and nonhorizontal angle corrections. For example, if composite average diameters, composite average nonhorizontal correction factors, and best approximations for specific gravities are used for the Southeast, the preceding formula for stems in the 0.25 to ≤1.0 in. size class simplifies to:

$$Tons/Acre = \frac{2.24(n)}{N \times l} \tag{7}$$

where

n = total number of intersections (i.e., counts) on all transects

N = number of transects

l = length of transect in feet

For stems in the >1.0 to 3.0 in. size class the formula simplifies to:

$$Tons/Acre = \frac{21.4(n)}{N \times l} \tag{8}$$

where

n = total number of intersections (i.e., counts) on all transects

N = number of transects

l = length of transect in feet

For stems in the >3.0 in. size class the formula simplifies to:

$$Tons/Acre = \frac{6.87\ (\Sigma\ d^2)}{N \times 1} \tag{9}$$

where

Σd^2 = the sum of the squared diameter of each intersecting stem

N = number of transects

l = length of transect in feet

(3) Sum the tons per acre for the three size classes and convert to cubic feet per acre:

$$Cubic\ Feet/Acre = \frac{Tons/Acre \times 32.05}{0.58} \tag{10}$$

(4) Convert cubic feet per acre to cubic meters per ha by multiply cubic feet per acre by 0.072.

(5) Report woody debris volume in cubic meters per hectare.

In western Kentucky reference wetlands, the volume of woody debris ranged from zero to 80 m^3/ha (Appendix D). Based on data from reference standard sites, a variable subindex of 1.0 is assigned to sites with woody debris between 20-50 m^3/ha (Figure 22). Below 20 m^3/ha the subindex decreases linearly to 0.0. This range of values included reference sites that had been converted to agriculture and had little or no woody debris, sites in early stages of succession with low volumes of woody debris, and sites in the middle stages of succession with a volume of woody debris between 10-20 m^3/ha. The decrease in the variable subindex is based on the assumption that lower volumes of woody debris indicate an inadequate reservoir of nutrients and the inability to maintain characteristic nutrient cycling over the long term. Above 50 m^3/ha the subindex also decreases linearly to 0.0 at 150 m^3/ha. This is based on the assumption that increasingly higher volumes of woody debris indicate that nutrient cycles are out of balance and that high levels of nutrients are locked up in the long-term storage component and unavailable for primary production in the short term. This situation occurs after logging or catastrophic wind damage.

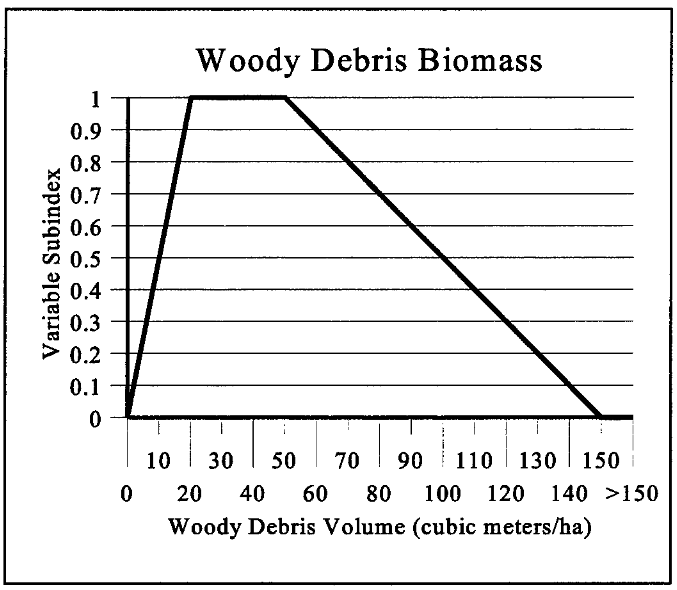


Figure 22. Relationship between woody debris and functional capacity

Functional capacity index

The assessment model for the Cycle Nutrients function is:

$$FCI = \left[\frac{\left(\frac{V_{TBA} + V_{SSD} + V_{BVC}}{3} \right) + \left(\frac{V_{OHOR} + V_{AHOR} + V_{WD}}{3} \right)}{2} \right] \tag{11}$$

In the model, the capacity of the riverine wetland to cycle nutrients depends on two characteristics. The first is the presence of all strata of the plant community, represented in the first part of the model by the variables V_{TBA}, V_{SSD} , and V_{GVC}. These partially compensatory variables (WRP in preparation, Chapter 4) are combined using an arithmetic mean. This is based on an assumption of equal importance for each strata of the plant community and the fact that the total loss of one of the strata (i.e., a variable subindex of 0.0) does not cause nutrient cycling to cease, just to be reduced.

The second characteristic, the presence of the long- and short-term detrital and soil components, is represented in the second part of the model by the variables $V_{OHOR,}$ $V_{AHOR,}$ and V_{WD}. These partially compensatory variables are averaged based on the assumption that all detrital components are given equal importance in nutrient cycling.

The two parts of the model are averaged because production and decomposition processes in nutrient cycling are considered to be interdependent and equally important. Hence a characteristic level of nutrient cycling will not be achieved (i.e., an FCI of 1.0) if nutrient cycling processes related to primary production or decomposition are reduced. An arithmetic, rather than a geometric, mean is used in recognition of the fact that it is possible under certain situations for variable subindices to drop to 0.0 for short periods of time. For example, high velocity currents associated with overbank floods can physically remove detrital components for short periods of time. However, as long as the three strata of plant community are present, the primary production component of nutrient cycling will continue, detrital stocks will be replenished quickly, and nutrient cycling will continue at high levels.

Function 4: Remove and Sequester Elements and Compounds

Definition

Remove and Sequester Elements and Compounds is defined as the ability of the riverine wetland to permanently remove or temporarily immobilize nutrients, metals, and other elements and compounds that are imported to the riverine wetland from upland sources and via overbank flooding. In a broad sense, elements include macronutrients essential to plant growth (nitrogen, phosphorus, and potassium) and other elements such as heavy metals (zinc, chromium, etc.) that can be toxic at high concentrations. Compounds include pesticides and other imported materials. The term "removal" means the permanent loss of elements and compounds from incoming water sources (e.g., deep burial in sediments, loss to the atmosphere), and the term "sequestration" means the short- or long-term immobilization of elements and compounds. A potential

independent, quantitative measure of this function is the quantity of one or more imported elements and compounds removed or sequestered per unit area during a specified period of time (e.g., $g/m^2/yr$).

Rationale for selecting the function

The role of riverine wetlands as interceptors of elements and compounds from upland or aquatic nonpoint sources is widely documented (Lowrance et al. 1984; Peterjohn and Correll 1984; Cooper, Gilliam, and Jacobs 1986; Cooper et al. 1987). Riverine wetlands in headwater and lower order streams are strategically located to intercept elements and compounds originating in the adjacent upland areas before they reach streams (Brinson 1993b). Riverine wetlands on higher order streams have also been found to remove elements from overbank floodwater (Mitsch, Dorge, and Wiemhoff 1979). The primary benefit of this function is simply that the removal and sequestration of elements and compounds by riverine wetlands reduce the load of nutrients, heavy metals, pesticides, and other pollutants in rivers and streams. This translates into better water quality and aquatic habitat in rivers and streams.

Characteristics and processes that influence the function

There are two categories of characteristics and processes that influence the capacity of riverine wetlands to remove and sequester elements and compounds. The first deals with the mechanisms by which elements and compounds are transported to the wetland, and the second deals with the structural components and biogeochemical processes involved in removal or sequestration of the elements and compounds.

Elements and compounds are imported to riverine wetlands by a variety of mechanisms and from a variety of sources. They include dry deposition and precipitation from atmospheric sources, overbank flooding from alluvial sources, and overland flow, channelized flow, interflow, shallow groundwater flow, and colluvial material from upland sources. Some of the mechanisms, such as dry deposition and precipitation, typically account for a small proportion of the total quantity of elements and compounds imported to the riverine wetland. More importantly, these mechanisms are not typically impacted, particularly from the 404 perspective. The mechanisms that bring nutrients and compounds to the wetland from alluvial and upland sources are more important in terms of both the quantity of elements and compounds and their likelihood of being impacted.

Once nutrients and compounds arrive in the riverine wetland, they may be removed and sequestered through a variety of biogeochemical processes. Biogeochemical processes include complexation, chemical precipitation, adsorption, denitrification, decomposition to inactive forms, hydrolysis, uptake by plants, and other processes (Kadlec 1985, Faulkner and Richardson 1989, Johnston 1991). A major mechanism that contributes to removal of elements and compounds from water entering a wetland is reduction. Denitrification will not occur unless the soil is anoxic and the redox potential falls below a certain level. When this occurs, nitrate (NO_3^-) removed by denitrification is released as nitrogen gas to the atmosphere. In addition, sulfate is reduced to sulfide which then reacts with metal cations to form insoluble metal sulfides such as CuS, FeS, PbS, and others.

Another major mechanism for removal of elements and compounds is by adsorption to electrostatically charged soil particles. Clay particles and particulate organic matter are the most highly charged soil particles and contribute the most to the cation exchange capacity (CEC) of the soil. Cation exchange is the interchange between cations in solution and other cations on the surface of any active material (i.e., clay colloid or organic colloid). The sum total of exchangeable cations that a soil can adsorb is the cation exchange capacity. The CEC of a soil is a function of the amount and type of clay and the amount of organic matter in the soil. Further, organic matter is a food source for microbes involved in various microbial processes (i.e., reduction-oxidation reactions, denitrification, microbial pesticide degradation, etc.).

Nitrogen in the ammonium (NH_4^+) form may be sequestered by adsorption to clay minerals in the soil. Phosphorus can only be sequestered, not truly removed. The soluble orthophosphate ion (PO_4^{3-}) may be specifically adsorbed ("fixed") to clay and Fe and Al oxide minerals (Richardson 1985) which are generally abundant in riverine wetlands. Likewise, heavy metals can be sequestered from incoming waters by adsorption onto the charged surfaces (functional groups) of clay minerals by specific adsorption onto Fe and Al oxide minerals or by chemical precipitation as insoluble sulfide compounds. Direct measurement of concentrations of these soil components is beyond the scope of rapid assessment. However, soils with pH of 5.5 or less generally have Al oxide minerals present that are capable of adsorbing phosphorus and metals. Fe oxides are reflected in brown or red colors in surface or subsoil horizons, either as the dominant color or as redox concentrations. If the Fe oxide minerals become soluble by reduction, adsorbed phosphorus is released into solution. Annual net uptake of phosphorus by growing vegetation, although significant, usually represents a small quantity relative to other soil/sediment sinks of phosphorus (Brinson 1985). Riverine wetlands also retain nutrients and compounds by storing and cycling them among the plant, animal, detrital, and soil compartments (Patrick and Tusneem 1972; Kitchens et al. 1975; Brinson 1977; Day, Butler, and Conner 1977; Mitsch, Dorge, and Wiemhoff 1979; Yabro 1983; Brinson, Bradshaw, and Kane 1984; Yarbro et al. 1984; Godshalk, Kleiss, and Nix in prep.).

Description of model variables

Overbank flood frequency (V_{FREQ}). This variable represents the frequency at which water from a stream overtops its banks (i.e., exceeds channel-full discharge) and inundates riverine wetlands on the floodplain. Overbank flood frequency is the manifestation of current conditions in the watershed and channel at the spatial scale of the riverine wetland. In the context of this function, overbank flooding is the mechanism by which nutrients and compounds are imported to the riverine wetland from alluvial sources. A characteristic return interval makes it possible for removal and sequestration processes to take place. However, overbank flooding is also important in setting up the chemical environment (oxidation/reduction potentials, pH, etc.) which mediates the removal of elements and compounds.

Recurrence interval in years is used to quantify this variable. The procedure for measuring it is described on page 24.

In western Kentucky reference wetlands, using regional dimensionless curves, recurrence interval ranged from 1-25 years (Appendix D). Based on the range of values from reference standard sites, a variable subindex of 1.0 is assigned to recurrence intervals ≤1.0 year (Figure 23). Longer recurrence intervals are assigned a linearly decreasing subindex to 0.1 at a

recurrence interval of 10 years. This is based on the assumption that where entrenchment, channelization, or levees effectively increase the depth of the stream channel, a greater discharge is required to overtop the bank and inundate the riverine wetland. Since greater discharges occur less frequently, the frequency at which surface water delivered to riverine wetlands is less than what characteristically occurs at reference standard sites. The rationale for the rate at which the subindex drops to 0.1 (i.e., 1.0 to 0.1) is based on the assumption that, as frequency increases, the capacity of the wetland to store annual peak discharges decreases to one-tenth the amount of water stored over a period of 10 years under reference standard conditions. Recurrence intervals >10 years are assigned a subindex of 0.1. This is based on the assumption that, even at longer recurrence intervals, riverine wetlands receive floodwater, albeit infrequently. Again, conceptual arguments can be made for dropping the subindex to zero, but it is difficult to determine at what point an increasing recurrence interval begins to significantly influence the ecological processes linked to overbank flooding.

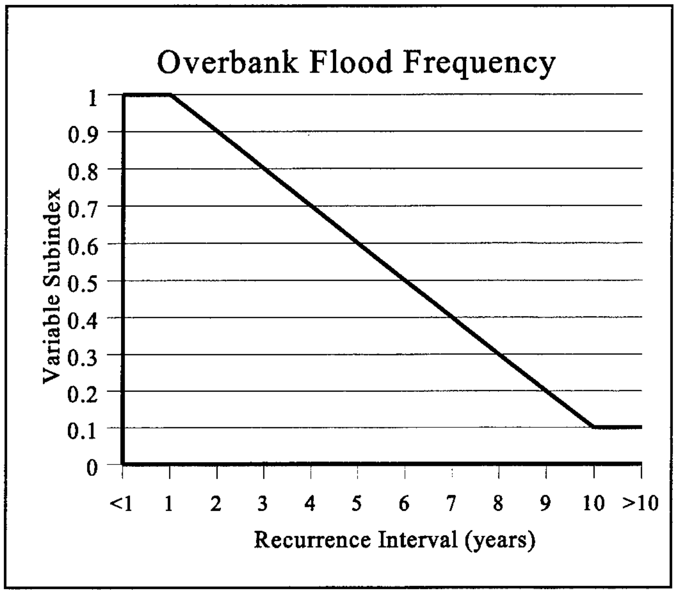


Figure 23. Relationship between recurrence interval and functional capacity

Water Table Depth (V_{WTD}). This variable represents the depth to seasonal high water table in the riverine wetland. In the context of this function, this variable indicates whether or not groundwater contributes to maintaining a hydrolgic regime that is conducive to the biogeochemical processes that remove and sequester elements and compounds.

Depth to the seasonal high water table is used to quantify this variable. Measure it with the following procedure.

(1) Determine the depth to the current seasonal high water table by using the following criteria (in order of accuracy and preference):

(a) groundwater monitoring well data collected over several years

(b) redoximorphic features such as iron concentrations, reaction to *a,a'* dipyridyl, or the presence of a reduced soil matrix (Verpraskas 1994; Hurt, Whited, and Pringle 1996), remembering that some redoximorphic features reflect a soil that has been anaerobic at some time in the past, but do not necessarily reflect current conditions

(c) the presence of a seasonal high water table according to the Soil and Water Features Table in modern County Soil Surveys. In situations where the fluctuation of the water table has been altered as a result of raising the land surface above the water table through the placement of fill, the installation of drainage ditches, or

drawdown by water supply wells, the information in the soil survey is no longer useful. Under these circumstances, the use of well data or redoximorphic features that indicate current conditions may be the only way to obtain the necessary information.

(2) Report depth to seasonal high water table in inches.

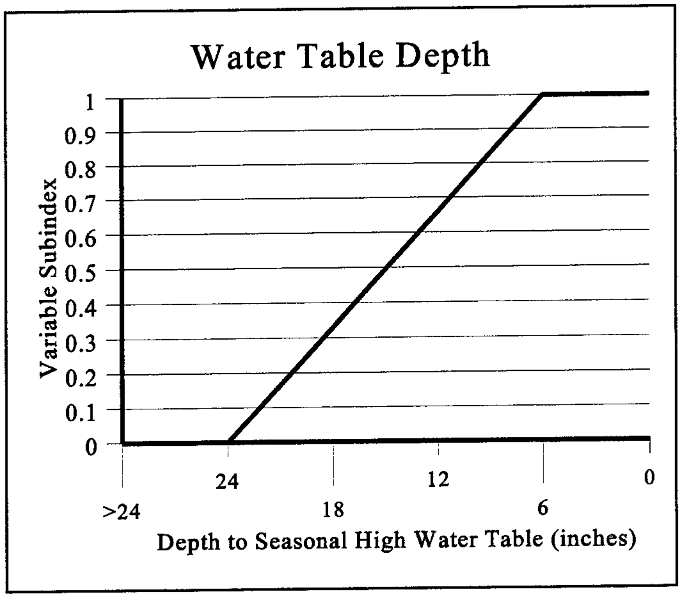


Figure 24. Relationship between depth to seasonal high water table and functional capacity (negative values are above the surface)

In western Kentucky reference wetlands, the depth to seasonal high water table ranged from zero to 18 in. below the surface (Appendix D). Based on the range of values from reference standard sites, a variable subindex of 1.0 was assigned to seasonal high water table "depths" between zero (i.e., ground surface) and 6 in. below the surface (Figure 24). As the depth to the seasonal high water table increases (i.e., is farther below the surface of the ground), the subindex decreases linearly to zero at a depth of 24 in. This is based on the assumption that the capacity of the riverine wetland to maintain the degree of soil saturation required for characteristic biogeochemical processes and plant and animal communities is dependent on a characteristic seasonal high water table near or above the surface of the ground.

Soil clay content (V_{CLAY}). This variable represents the proportion of the total charge in the top 50 cm (20 in.) of the soil profile that originates from the clay fraction or separate. One of the mechanisms that contributes to retention of elements and compounds is adsorption to charged sites on soil particles. The adsorption capacity of a soil is reflected by the CEC and anion exchange capacity (AEC) which originate from electrostatic charges on organic and mineral particles in the soil. Within the mineral fraction, most of the charge originates from clay-sized particles (<0.002 mm) because of surface area and types of minerals present in this size separate. The amount and mineralogy of the clay (i.e., whether smectite, mica, vermiculite, kaolinite, etc.) determine the total charge, either positive or negative, derived from clay particles. The pH and total concentration of ions in the soil solution within the horizon can also affect the total charge, especially for soils with high amounts of kaolinite, Fe and Al oxides, and other variable-charge components. These variable-charge components are present in minor quantities in western Kentucky, however, and clay mineralogy is relatively uniform (Karathanasis et al. 1988). Thus, the amount of clay within a horizon can be used to reflect the total nonorganic charge for the horizon.

Most of the impacts that riverine wetlands are subjected to do not significantly change the amount or type of clay in the soil profile. However, some impacts such as the placement of fill

material, or the excavation and replacement of soil can significantly alter the amount or type of clay, and consequently the charge characteristics of the soil and the ability of the wetland to retain elements and compounds.

The percent difference in clay content in the top 50 cm (20 in.) of the soil profile in the assessment area is used to quantify this variable. Measure it with the following procedure.

(1) Determine if the native soil in any of the area being assessed has been covered with fill material, excavated and replaced, or subjected to any other types of impact that significantly change the clay content of the top 50 cm (20 in.) of the soil profile. If no such alteration has occurred, assign the variable subindex a value of 1.0 and move on to the next variable. A value of 1.0 indicates that none of the soils in the area being assessed have an altered clay content in the top 50 cm (20 in.).

(2) If the soils in part of the area being assessed have been altered in one of the ways described above, estimate the soil texture for each soil horizon in the upper 50.8 cm (20 in.) in representative portions of these areas. Soil particle size distribution can be measured in the laboratory on samples taken from the field, or the percent of clay can be estimated from field texture determinations done by the "feel" method. Appendix C describes the procedures for estimating texture class by feel.

(3) Based upon the soil texture class, determined in the previous step, the percentage of clay is determined from the soil texture triangle. The soil texture triangle contains soil texture classes and the corresponding percentages of sand, silt, and clay which comprise each class. Once the soil texture is determined by feel, the corresponding clay percentage is read from the left side of the soil texture triangle. The median value from the range of percent clay is used to calculate the weighted average. For example, if the soil texture at the surface was a silty clay loam, the range of clay present in that texture class is 28-40 percent. A median value of 34 percent would be used for the clay percentage in that particular horizon.

(4) Calculate a weighted average of the percent clay in the altered soil by averaging the percent clay from each of the soil horizons to a depth of 50.8 cm (20 in.). For example, if the A horizon occurs from a depth of 0-12.7 cm (0-5 in.) and has 30 percent clay, and the B horizon occurs from a depth of 15.2-50.8 cm (6-20 in.) and has 50 percent clay, then the weighted average of the percent clay for the top 50.8 cm (20 in.) of the profile is $((5 \times 30) + (15 \times 50)) / 20 = 45$ percent.

(5) Calculate the difference in percent clay between the natural soil (i.e., what existed prior to the impact) and the altered soil using the following formula: percent difference = $((\,|\,\%\text{ clay after alteration} - \%\text{ clay before alteration}\,|\,) / \%\text{ clay before alteration})$. For example, if the percentage of clay after alteration is 40 percent, and the percentage of clay before alteration is 70 percent, then $|\,40 - 70\,| = 30$, and $(30 / 70) = 43$ percent.

(6) Average the results from representative portions of the altered area.

(7) Multiply the percent difference for each altered area by the percent of the riverine wetland being assessed that the area represents (Column 3 in Table 12).

Table 12
Calculating Percent Difference of Clay in Soils of Wetland Assessment Area

Area Description	Average Percent Difference in Clay Content in the Area	Percent of Area Being Assessed Occupied by the Area	Column 2 Multiplied by Column 3
Altered area 1	43% (0.43)	10% (0.10)	0.043
Altered area 2	60% (0.50)	10% (0.10)	0.05
Unaltered area	0.0% (0)	80% (0.80)	0
Percent difference = (sum of column 4) × 100 = 9.3 %			0.093

(8) Sum values in Column 4 and multiply by 100 to obtain the percent difference (last row in Table 12).

(9) Report the percent difference in the soil clay content in the area being assessed.

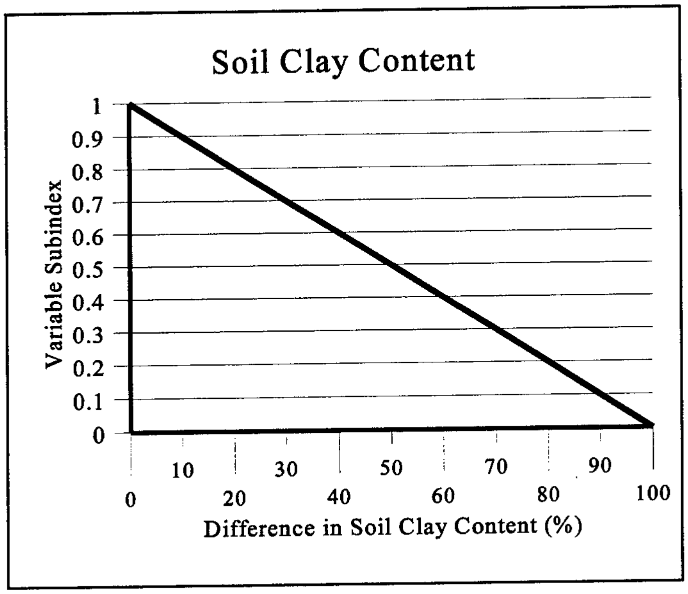


Figure 25. Relationship between the percent difference in soil clay in the wetland assessment area and functional capacity

In western Kentucky reference wetlands, the percent of the difference in clay content in the area assessed was zero (Appendix D). At reference standard wetland sites, the percent difference in clay content was also zero. This is expected since this variable is designed to detect project impacts which result in significant changes in soil clay content, and reference standard sites are by definition the least altered wetlands in the reference domain. Therefore, no alteration (i.e., zero alteration) in the clay content of the soil is assigned a subindex value of 1.0. As the percent difference in soil clay content increases, a linearly decreasing subindex down to zero at 100 percent alteration is assigned (Figure 25). This is based on the assumption that, as the percent difference in soil clay content increases, the capacity of the soil to adsorb cations decreases linearly. These assumptions can be validated using an independent, quantitative measure of function identified above.

Redoximorphic features (V_{REDOX}). This variable represents the reduction and oxidation history of the soil in a riverine wetland. Hydric soil indicators include redoximorphic features, accumulation of organic matter, or other indicators discussed in the National Technical Committee for Hydric Soils publication on hydric soil indicators (Hurt, Whited, and Pringle 1996). The presence of hydric soil indicators implies adequate soil saturation for a sufficient duration to induce reduction in the top 30.5 cm (12 in.) of the soil profile. It is assumed that soil reduction in the upper part has more influence on the wetland ecosystem than at greater depths. The presence

of redoximorphic features anywhere in the top 30.5 cm (12 in.) is positive evidence that the soil is undergoing periodic reduction and oxidation, a major mechanism in the removal of elements and compounds in the soil profile. Most of these redoximorphic features are associated with reduction and oxidation of Fe which occur at a redox potential between that needed for reduction of nitrate (denitrification) and that needed for sulfate reduction. Thus, the presence of redoximorphic features in the soil indicates that denitrification has occurred. However, this provides no information on the formation of sulfides. Sulfide odor could be used as an indicator, but this will vary seasonally as the water table fluctuates.

The presence of hydric soil indicators varies widely among and within soils depending on season, frequency and duration of saturation, amount and type of organic C, and other factors. Consequently, no attempt is made to develop a relationship between this variable and functional capacity based on the degree or expression of hydric soil indicators. Rather, the variable is designed to indicate whether or not reduction occurs sometime during the year in most years, based on the presence or absence of redoximorphic features in the soil.

The presence or absence of redoximorphic features is used to categorize this variable. Determine the appropriate category with the following procedure.

(1) Observe the top 30.5 cm (12 in.) of the soil profile and determine if redoximorphic features, accumulation of organic matter, or other hydric soil indicators are present or absent.

(2) Report redoximorphic features as present or absent.

In western Kentucky reference wetlands, redoximorphic features ranged from present to absent (Appendix D). Based on the presence of redoximorphic features at all reference standard sites, a variable subindex of 1.0 was assigned to the presence of redoximorphic features (Figure 26). Sites where redoximorphic features are absent are assigned a subindex of 0.1 based on the assumption that, even in the absence of redoximorphic features, reduction takes place at some low level.

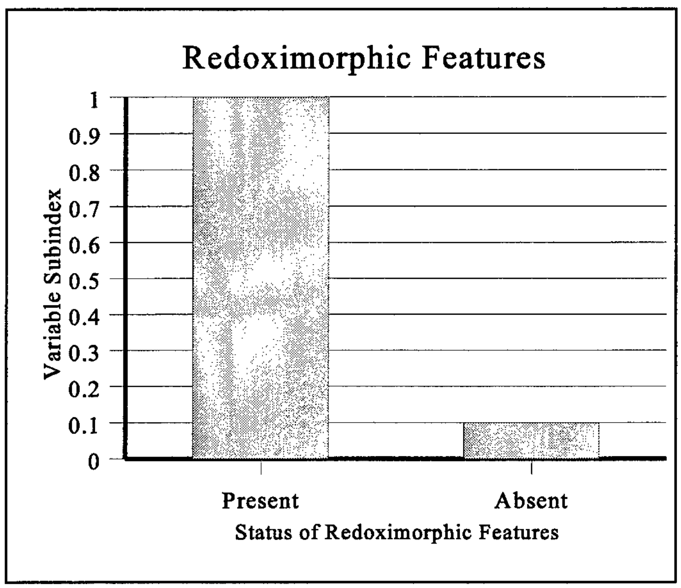


Figure 26. Redoximorphic features and functional capacity

"O" horizon biomass (V_{OHOR}). This variable represents the total mass of organic matter in the "O" horizon. The "O" horizon is defined as the soil layer dominated by organic material that consists of recognizable or partially decomposed organic matter such as leaves, needles, sticks or twigs < 0.6 cm in diameter, flowers, fruits, insect frass, moss, or lichens on or near the surface of the ground (USDA SCS 1993). The "O" horizon is synonymous with the term detritus or litter layer used by other

disciplines. In the context of this function, the "O" horizon represents a component of the organic matter which can sequester imported elements and compounds by adsorption.

Percent cover of the "O" soil horizon is used to quantify this variable. Measure it with the procedure described on page 47.

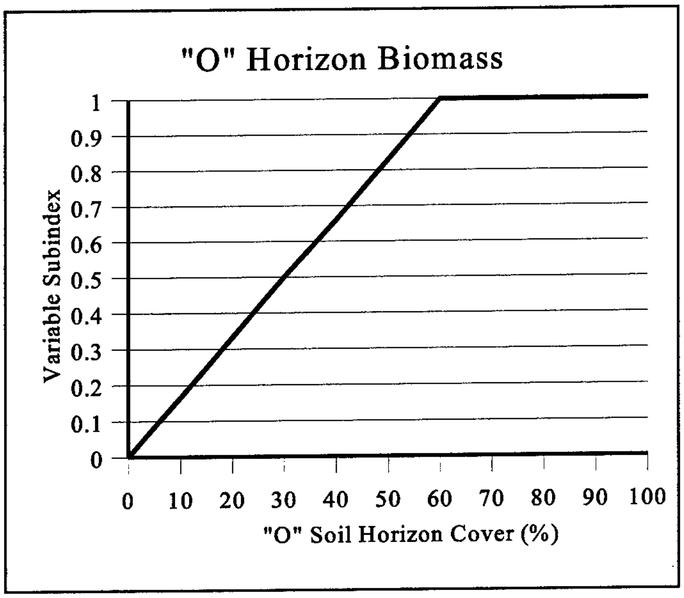


Figure 27. Relationship between "O" soil horizon and functional capacity

In western Kentucky reference wetlands, percent "O" horizon cover ranged from zero to 100 percent (Appendix D). Based on data from reference standard sites, a variable subindex of 1.0 is assigned when the "O" soil horizon cover is >60 percent (Figure 27). As "O" horizon cover decreases, a linearly decreasing subindex down to zero at zero percent cover is assigned. The rate at which the subindex decreases, and the selection of zero as the subindex endpoint at 100 percent cover, is based on the assumption that the relationship between "O" soil horizon cover and removal and sequestration of elements and compounds is linear and that a decreasing amount of biomass in the tree, sapling, shrub, and ground vegetation strata of the plant community is reflected in lower percent "O" soil horizon cover. When percent "O" soil horizon drops to zero, sequestration by organic matter has essentially ceased. These assumptions could be validated using the independent, quantitative measures of function defined above.

"A" horizon biomass (V_{AHOR}). This variable represents total mass of organic matter in the "A" horizon. The "A" horizon is defined as a mineral soil horizon that occurs at the ground surface, or below the "O" soil horizon, and consists of an accumulation of unrecognizable decomposed organic matter mixed with mineral soil (USDA SCS 1993). In addition, for the purposes of this procedure, in order for a soil horizon to be considered an "A" horizon, it must be at least 7.6 cm (3 in.) thick and have a Munsell color value less than or equal to 4. In the context of this function, the "A" horizon represents another reservoir of organic matter which is available to adsorb elemental compounds.

Percent cover of the "A" soil horizon is used to quantify this variable. Measure it with the procedure described on page 48.

In western Kentucky reference wetlands, "A" horizon cover ranged from zero to 100 percent (Appendix D). Based on data from reference standard sites, a variable subindex of 1.0 is assigned when the percent cover of the "A" horizon is >80 percent (Figure 28). As the percent cover of the "A" horizon decreases, a linearly decreasing subindex down to zero at zero percent cover is assigned. This is based on the assumption that the relationship between percent "A"

horizon and the capacity to remove and sequester elements and compounds is linear and reflects decreasing contribution to "A" horizon biomass by the tree, sapling, shrub, and ground vegetation strata of the plant community. Sites that have been converted to agricultural crops may have low coverage of the "A" horizon due to the oxidation of the organic carbon following tillage (Ismail, Blevins, and Frye 1994).

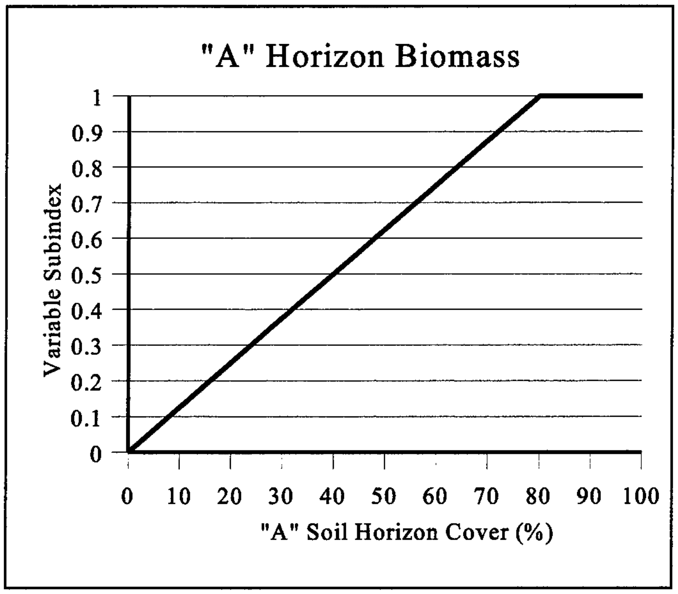


Figure 28. Relationship between "A" soil horizon and functional capacity

Functional capacity index

The assessment model for deriving the functional capacity index is as follows:

$$FCI = \left[\left(\frac{V_{FREQ} + V_{WTD}}{2} \right) \times \left(\frac{V_{CLAY} + V_{REDOX} + V_{OHOR} + V_{AHOR}}{4} \right) \right]^{1/2} \quad (12)$$

In the first part of the model, recurrence interval (V_{FREQ}) indicates whether or not elements and compounds are being imported from alluvial sources. Seasonal high water table depth (V_{WTD}) indicates whether or not groundwater contributes to maintaining a hydrolgic regime that is conducive to the biogeochemical processes that remove and sequester elements and compounds. The two variables are partially compensatory based on the assumption that they are independent and contribute equally to performance of the function. The two variables are combined using an arithmetic mean because elements and compounds will continue to be imported to the wetland even if the value of the V_{WTD} subindex drops to 0.0.

In the second part of the model, four variables, all indicating different mechanisms for removing or sequestering imported elements and compounds, are partially compensatory since they are assumed to be independent and to contribute equally to performance of the function. V_{CLAY}, V_{AHOR}, and V_{OHOR} represent the adsorptive capacity of soils due to clays and organic matter, while V_{REDOX} represents the reducing environment and level of microbial activity needed for this function to occur. The four are combined using an arithmetic mean because elements and compounds will continue to be removed and sequestered even after V_{CLAY}, V_{AHOR}, and V_{OHOR} variable subindices drop to zero.

The two parts of the equation are partially compensatory and are combined using a geometric mean because if either subpart of the equation zeros, then the functional capacity should also drop to zero. This simply means that if elements and compounds are no longer imported to the riverine wetland, or if all the mechanisms that exist within the wetland for removing and sequestering elements and compounds are absent, then the riverine wetland has no capacity to remove elements and compounds.

Function 5: Retain Particulates

Definition

Retain Particulates is defined as the capacity of a wetland to physically remove and retain inorganic and organic particulates >0.45 μm (Wotton 1990) from the water column. The particulates may originate from either onsite or off-site sources. A potential independent, quantitative measure of this function is the amount of particulates retained per unit area per unit time (i.e., $g/m^2/yr$).

Rationale for selecting the function

Retention of particulates is an important function because sediment accumulation contributes to the nutrient capital of the riverine wetland. Deposition of inorganic particulates also increases surface elevation and changes topographic complexity, which has hydrologic, biogeochemical, and habitat implications. Particulate organic matter and woody debris may also be retained for decomposition, nutrient recycling, and detrital food web support. This function also reduces stream sediment load that would otherwise be transported downstream.

Characteristics and processes that influence the function

Three primary modes of water and sediment movement can be identified: (a) in-channel flow, (b) overbank flooding, and (c) overland flow (Molinas et al. 1988). Flooding during overbank flow is the primary mode for transporting inorganic particulates to floodplain wetlands. The movement of sediment can be described by the processes of initiation of motion, transport, and deposition. Initiation of motion is primarily a function of the energy available (e.g., falling raindrops or flowing water) and the nature of the sediment (e.g., more energy being required for bigger particles, and soils with well-developed root systems being more resistant to erosion). Once sediment particles are set in motion, the capacity of flows to transport sediment is primarily a function of water velocity, depth of flow, floodplain slope, and the size of the particles being carried (e.g., sand versus silt). Scour and deposition processes are adjustments to maintain a balance between amounts of sediment that overbank flows can carry and amount of sediment transported. If sediment load exceeds the ability of the water flow to carry the load (i.e., transport capacity), deposition occurs. On the other hand, if the sediment transport capacities exceed the amount of sediment being carried then scour is likely to occur.

In overbank flooding situations, water velocities drop sharply as water over-tops the bank and spreads onto the floodplain. The reductions in transport capacity result in deposition. Under reference standard conditions, low gradient, riverine, forested wetlands have well-developed canopy and litter layers that absorb kinetic energy of precipitation (i.e., less energy to detach sediment). They also have high surface roughness coefficients that produce low velocities and low transport capacities thus retaining sediment within the wetland and producing deposition from overbank flows. However, much of the velocity reduction, and consequent reduction in transport capacity that facilitate deposition, is accounted for by floodwaters spreading out over large, flat areas rather than by the roughness of the site (Molinas et al. 1988). The same hydrodynamics that facilitate sedimentation may also capture and retain organic particulates. For

example, deposition of silt by winter floods following autumn litterfall appears to reduce the potential for leaves to become suspended by currents and exported (Brinson 1977). The Retention of Particulates function contrasts with Cycling of Nutrients and Removal and Sequestration of Imported Elements and Compounds because the emphasis is on physical processes (e.g., sedimentation and particulate removal). The processes involved in Retention of Particulates are similar to those involved in Temporary Storage of Surface Water; consequently, the variables for these two functions are identical. However, the rationale for including the variables differentiates the two functions.

Description of model variables

Overbank flood frequency (V_{FREQ}). This variable represents the frequency at which water from a stream overtops its banks (i.e., exceeds channel-full discharge) and inundates riverine wetlands on the floodplain. Overbank flood frequency is the manifestation of current conditions in the watershed and channel at the spatial scale of the riverine wetland. In the context of this function, overbank flooding is the mechanism by which particulates are imported to the riverine wetland from alluvial sources.

Recurrence interval in years is used to quantify this variable. The procedure for measuring this variable is described on page 24.

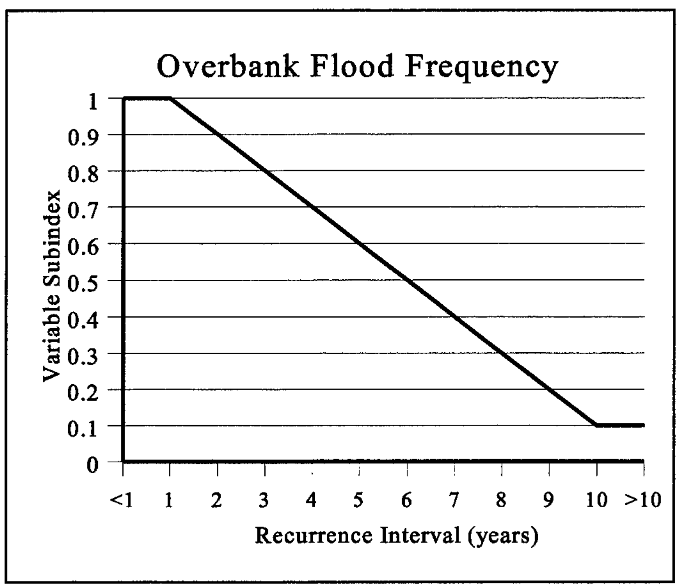


Figure 29. Relationship between recurrence interval and functional capacity

In western Kentucky reference wetlands, using regional dimensionless curves, recurrence interval ranged from 1-25 years (Appendix D). Based on the range of values from reference standard sites, a variable subindex of 1.0 is assigned to recurrence intervals ≤1.0 year (Figure 29). Longer recurrence intervals are assigned a linearly decreasing subindex to 0.1 at a recurrence interval of 10 years. This is based on the assumption that where entrenchment, channelization, or levees effectively increase the depth of the stream channel, a greater discharge is required to overtop the bank and inundate the riverine wetland. Since greater discharges occur less frequently, the volume of surface water that is temporarily stored and the amount of sediment delivered to riverine wetlands is less than what characteristically occurs at reference standard sites. The rationale for the rate at which the subindex drops to 0.1 (i.e., 1.0 to 0.1) is based on the assumption that, as frequency increases, the capacity of the wetland to retain particulates from annual peak discharges decreases to one-tenth the amount of particulates retained over a period of 10 years under reference standard conditions. Model validation will help to define the actual nature of this relationship. Recurrence intervals >10 years are assigned a subindex of 0.1. This

is based on the assumption that, even at longer recurrence intervals, riverine wetlands provide some floodwater storage and particulate retention, albeit infrequently. Again, conceptual arguments can be made for dropping the subindex to zero, but it is difficult to determine at what point an increasing recurrence interval begins to significantly influence the ecological processes linked to overbank flooding.

Floodplain storage volume (V_{STORE}). This variable represents the volume of space available for flood water to spread out, thus reducing transport capacity and retaining particulates, during overbank flood events in riverine wetlands. In western Kentucky, the loss of volume is usually a result of levees, roads, or other man-made structures reducing the effective width of the floodplain. Consequently, this variable is designed to detect alterations that result from these types of structures.

The ratio of floodplain width to channel width is used to quantify this variable. The procedure for measuring this variable is described on page 25.

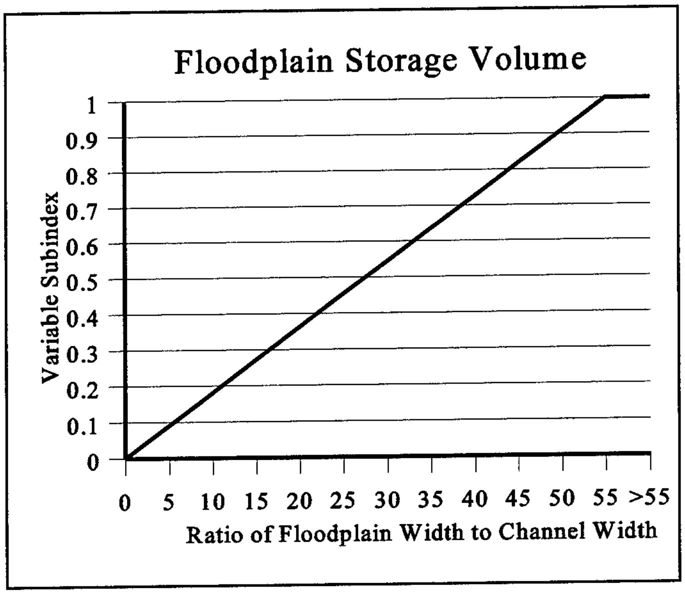


Figure 30. Relationship between the ratio of floodplain width to channel width and functional capacity

In western Kentucky reference wetlands, the ratio of floodplain width to channel width ranged from 8 to 360 (Appendix D). Based on the range of values at reference standard wetlands, a variable subindex of 1.0 is assigned to ratios ≥55 (Figure 30). Smaller ratios are assigned a linearly decreasing subindex down to zero at a ratio of 1. This is based on the assumption that ratio of floodplain width to channel width is linearly related to the capacity of riverine wetlands to temporarily store surface water and retain particulates.

Floodplain slope (V_{SLOPE}). This variable represents the slope of the floodplain adjacent to the riverine wetland being assessed. The relationship between slope and the retention of particulates is based on the proportional relationship between slope and velocity in Manning's equation (Equation 1). In layman's terms, the flatter the slope, the slower water moves through the riverine wetland. In the context of this function, this variable is designed to detect when the characteristic floodplain slope has been changed as a result of surface mining, placement of structures in the channel, or other activities that significantly alter floodplain slope.

The percent floodplain slope is used to quantify this variable. The procedure for measuring this variable is described on page 26.

In western Kentucky reference wetlands, floodplain slopes ranged from 0.03-0.5 percent (Appendix D). Reference standard wetland sites had floodplain slopes ranging from

0.03-0.05 percent. However, more extensive data from Wetzel and Bettandorff (1983) indicate that higher order rivers in western Kentucky typically have greater slopes, ranging from 0.06-0.09 percent (0.57-0.95 m/km (3-5 ft/mi)).

Based on the range of values at reference standard wetlands, a variable subindex of 1.0 is assigned to floodplain slopes ≤0.09 percent (Figure 31). As floodplain slope decreases, a linearly decreasing subindex is assigned down to 0.1 at a slope of 0.023 percent. This is based on an assumed linear relationship between slope and the capacity to retain particulates. Floodplain slopes ≥0.23 percent are assigned a subindex of 0.1 because, regardless of how steep the floodplain slope is, some particulates will always be retained during overbank events, albeit larger particle sizes.

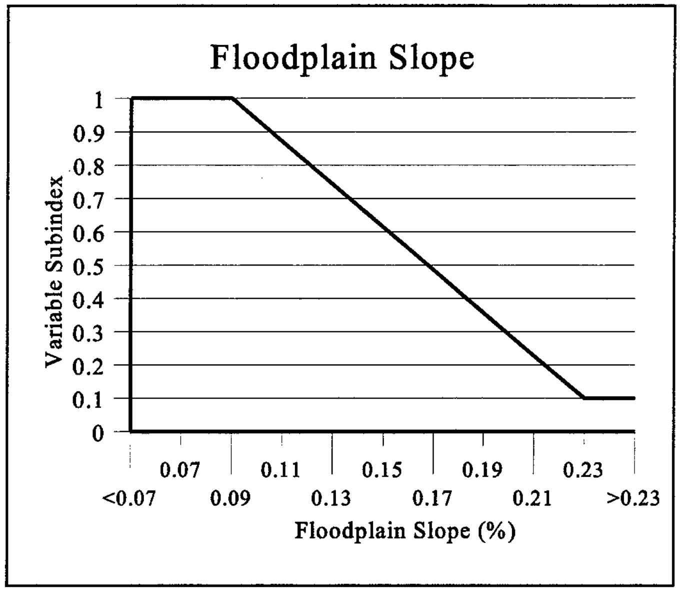


Figure 31. Relationship between floodplain slope and functional capacity

Floodplain roughness (V_{ROUGH}). This variable represents the resistance to the flow of surface water resulting from physical structure on the floodplain. The relationship between roughness and the velocity of surface water flow is expressed by Manning's equation, which indicates that, as roughness increases, velocity decreases and the ability of the water column to keep sediment particles entrained also decreases (Equation 1). Several factors contribute to roughness, including the soil surface, surface irregularities (e.g., micro- and macrotopographic relief), obstructions to flow (e.g., stumps and coarse woody debris), and resistance due to vegetation structure (trees, saplings, shrubs, and herbs). Depth of flow is also an important consideration in determining roughness because, as water depth increases, obstructions are overtopped and cease to be a source of friction or turbulence. Thus the roughness coefficient often decreases with increasing depth.

Manning's roughness coefficient (n) is used to quantify this variable. The procedure for measuring this variable is described on page 28.

In western Kentucky reference wetlands, Manning's roughness coefficient ranged from 0.04 to 0.20 (Appendix D). These values are based on setting n_{BASE} to 0.03, and adjustment values for the topographic relief component (n_{TOPO}) that ranged from 0.005-0.01, the obstructions component (n_{OBS}) that ranged from 0.01-0.05, and the vegetation component (n_{VEG}) that ranged from 0.05-0.15. Based on the range of values at reference standard sites, a variable subindex of 1.0 is assigned to Manning's roughness coefficients between 0.11 and 0.13 (Figure 32). Sites with higher roughness coefficients are also assigned a subindex of 1.0 based on the assumption that the increased roughness does not significantly increase retention time. Lower roughness coefficients were assigned a linearly decreasing subindex down to 0.5 at ≤0.03. This reflects the

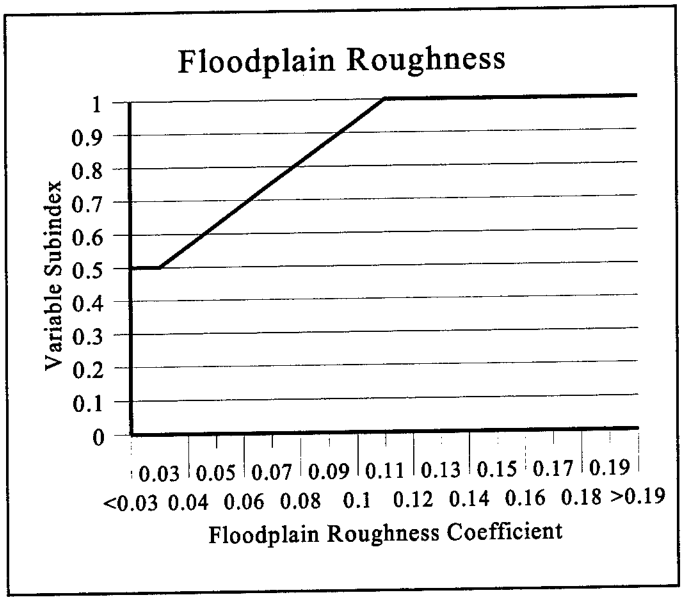


Figure 32. Relationship between floodplain roughness and functional capacity

approximate five-fold increase in flow velocity that occurs as floodplain roughness decreases from 0.11 to 0.03 when holding hydraulic radius and slope constant in Manning's equation.

Functional capacity index

The assessment model for calculating the functional capacity index is as follows:

$$FCI = \left[\left(V_{FREQ} \times V_{STORE} \right)^{1/2} \times \left(\frac{V_{SLOPE} + V_{ROUGH}}{2} \right) \right]^{1/2} \qquad (13)$$

In this model, the capacity of the riverine wetland to retain particulates depends on two characteristics, the ability of water to get to the site and the ability of the wetland to reduce the velocity of surface water moving through the site. In the first part, the V_{FREQ} variable indicates whether or not changes in the watershed or channel have altered the recurrence interval compared to reference standard sites. The V_{STORE} variable indicates whether or not structural alterations or fill have reduced the volume available for temporarily storing surface water, and thus retaining particulates.

The relationship between the variables is partially compensatory and they are assumed to contribute equally and independently to the performance of the function (WRP in preparation, Chapter 4). As the subindices for V_{FREQ} or V_{STORE} decrease, the FCI also decreases. If the subindex for V_{STORE} drops to zero, the FCI will also drop to zero because a geometric mean is used to combine V_{FREQ} and V_{STORE} as well as the first and second part of the model equation. This simply means that, as the frequency of inundation decreases or if the floodplain is greatly constricted by levees or roads, retention of particulates is reduced or eliminated. Use of an arithmetic mean to combine V_{FREQ} or V_{STORE} or the first and second part of the equation would require that subindices for all variables be zero in order for the resulting level of function to be zero which is clearly inappropriate in this situation.

In the second part of the model, V_{ROUGH} and V_{SLOPE} reflect the ability of the wetland to reduce the velocity of water moving through the wetland. These variables are also partially compensatory and assumed to be independent and to contribute equally to the performance of the function. In this however, the variables are combined using an arithmetic mean. Generally, this mathematical operation reduces the influence of lower value subindices on the FCI (Smith and Wakeley

1998) which in this case is consistent with the assumption that these variables have less of an influence on the function than either V_{FREQ} or V_{STORE}.

Function 6: Export Organic Carbon

Definition

Export Organic Carbon is defined as the capacity of the wetland to export the dissolved and particulate organic carbon produced in the riverine wetland. Mechanisms include leaching of litter, flushing, displacement, and erosion. An independent quantitative measure of this function is the mass of carbon exported per unit area per unit time ($g/m^2/yr$).

Rationale for selecting the function

The high productivity and close proximity of riverine wetlands to streams make them important sources of dissolved and particulate organic carbon for aquatic food webs and biogeochemical processes in downstream aquatic habitats (Vannote et al. 1980; Elwood et al. 1983; Sedell, Richey, and Swanson 1989). Dissolved organic carbon is a significant source of energy for the microbes that form the base of the detrital food web in aquatic ecosystems (Dahm 1981, Edwards 1987, Edwards and Meyers 1986). Evidence also suggests that the particulate fraction of organic carbon imported from uplands or produced in situ is an important energy source for shredders and filter-feeding organisms (Vannote et al. 1980).

Structural characteristics and processes that influence the function

Wetlands can be characterized as open or closed systems depending on the degree to which materials are exchanged with surrounding ecosystems (Mitsch and Gosselink 1993). Riverine wetlands normally function as open systems, primarily for two reasons. First, riverine wetlands occur in valley bottoms adjacent to stream channels. Since stream channels are the lowest topographic position in the landscape, water and sediments pass through the riverine wetlands as gravity moves them toward the stream channel. Second, under natural conditions, low gradient, riverine wetlands are linked to the stream channel through overbank flooding. In the case of the Export of Organic Carbon function the latter reason is of greatest importance.

Watersheds with a large proportion of riverine and other wetland types have generally been found to export organic carbon at higher rates than watersheds with fewer wetlands (Mulholland and Kuenzler 1979; Brinson, Lugo, and Brown 1981; Elder and Mattraw 1982; Johnston, Detenbeck, and Niemi 1990). This is attributable to several factors, including: (a) the large amount of organic matter in the litter and soil layers that comes into contact with surface water during inundation by overbank flooding, (b) relatively long periods of inundation and, consequently, contact between surface water and organic matter, thus allowing for significant leaching, (c) the ability of the labile carbon fraction to be rapidly leached from organic matter when exposed to water (Brinson et al. 1981), and (d) the ability of floodwater to transport dissolved and particulate organic carbon from the floodplain to the stream channel.

Description of model variables

Overbank flood frequency (V_{FREQ}). This variable represents the frequency at which water from a stream overtops its banks (i.e., exceeds channel-full discharge) and inundates riverine wetlands on the floodplain. Overbank flood frequency is a manifestation of current conditions in the watershed and channel at the spatial scale of the riverine wetland. In the context of this function, overbank flooding is the mechanism by which organic carbon is exported from riverine wetlands.

Recurrence interval in years is used to quantify this variable. The procedure for measuring it is described on page 24.

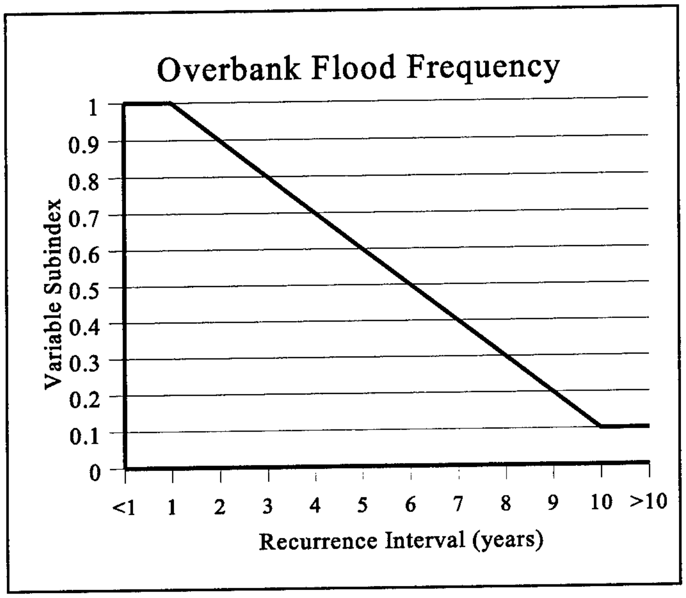


Figure 33. Relationship between recurrence interval and functional capacity

In western Kentucky reference wetlands, using regional dimensionless curves, recurrence interval ranged from 1-25 years (Appendix D). Based on the range of values from reference standard sites, a variable subindex of 1.0 is assigned to recurrence intervals ≤1.0 year (Figure 33). Longer recurrence intervals are assigned a linearly decreasing subindex to 0.1 at a recurrence interval of 10 years. This is based on the assumption that where entrenchment, channelization, or levees effectively increase the depth of the stream channel, a greater discharge is required to overtop the bank and inundate the riverine wetland. Since greater discharges occur less frequently, the delivery of water to export carbon from the riverine wetlands is less than what characteristically occurs at reference standard sites. The rationale for the rate at which the subindex drops to 0.1 (i.e., 1.0 to 0.1) is based on the assumption that, as frequency increases, the capacity of the wetland to export carbon during annual peak discharges decreases to one-tenth the amount of carbon exported over a period of 10 years under reference standard conditions. Model validation will help to define the actual nature of this relationship. Recurrence intervals >10 years are assigned a subindex of 0.1. This is based on the assumption that even at longer recurrence intervals, riverine wetlands export some carbon, albeit infrequently. Again, conceptual arguments can be made for dropping the subindex to zero, but it is difficult to determine at what point an increasing recurrence interval begins to significantly influence the ecological processes linked to overbank flooding.

Surface water connections ($V_{SURFCON}$). This variable represents the internal network of shallow surface water channels that usually connect the riverine wetland to the stream channel on low gradient, riverine floodplains. Typically, these channels intersect the river channel through low spots in the natural levee. When water levels are below channel full, these channels serve as the route for surface water, and the dissolved and particulate organic matter it carries, as it moves

from the floodplain to the stream channel. This same network of channels routes overbank floodwater to riverine wetlands during the early stages of overbank flooding.

This variable is designed to indicate, at a relatively coarse level of resolution, when project impacts reduce or eliminate the surface water connection between the riverine wetland and the adjacent stream channel. Levee construction and side-cast dredging are typical project impacts that reduce or eliminate these surface water connections and, as a result, reduce the export of organic carbon.

The percentage of the linear distance of stream reach that has been altered is used to quantify this variable. Measure it with the following procedure.

(1) Conduct a visual reconnaissance of the area being assessed and the adjacent stream reach. Estimate what percent of this stream reach has been modified with levees, side-cast materials, or other obstructions that reduce the exchange of surface water between the riverine wetland being assessed and the stream channel.

(2) Report percent of the linear distance of the stream reach that has been altered.

In western Kentucky reference wetlands, the percentage of the linear distance of stream reach that had been altered ranged from zero to 100 percent (Appendix D). Based on the range of values from reference standard sites, a variable subindex of 1.0 was assigned when surface connections are unaltered (Figure 34). A variable subindex of 1.0 is assigned when zero percent of the stream reach is altered. As the percentage of the altered stream reach increases, a decreasing subindex is assigned down to zero when 100 percent of the stream reach is altered. This is based on the assumption that the relationship between surface water connnections and carbon export is linear.

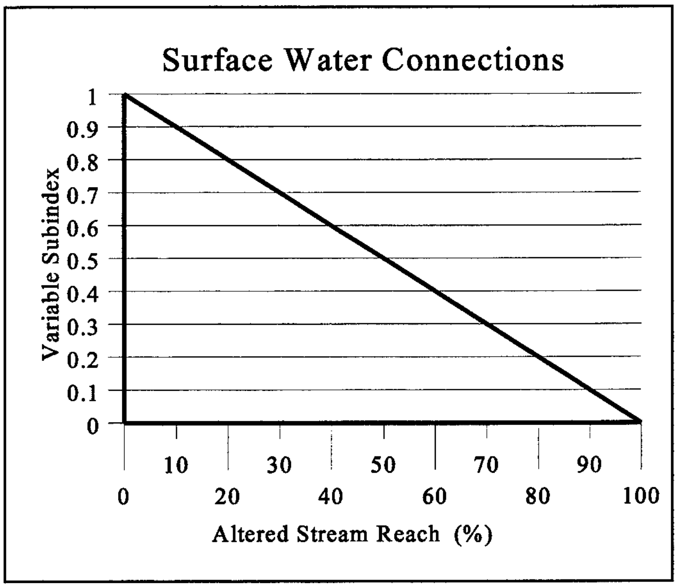


Figure 34. Relationship between surface water connections and functional capacity

"O" horizon biomass (V_{OHOR}). This variable represents the total mass of organic matter in the "O" horizon. The "O" horizon is defined as the soil layer dominated by organic material that consists of recognizable or partially decomposed organic matter such as leaves, needles, sticks or twigs < 0.6 cm in diameter, flowers, fruits, insect frass, moss, or lichens on or near the surface of the ground (USDA SCS 1993). The "O" horizon is synonymous with the term detritus or litter layer used by other disciplines. In the context of this function, the "O" horizon represents organic carbon available for export.

Percent cover of the "O" soil horizon is used to quantify this variable. The procedure for measuring it is described on page 47.

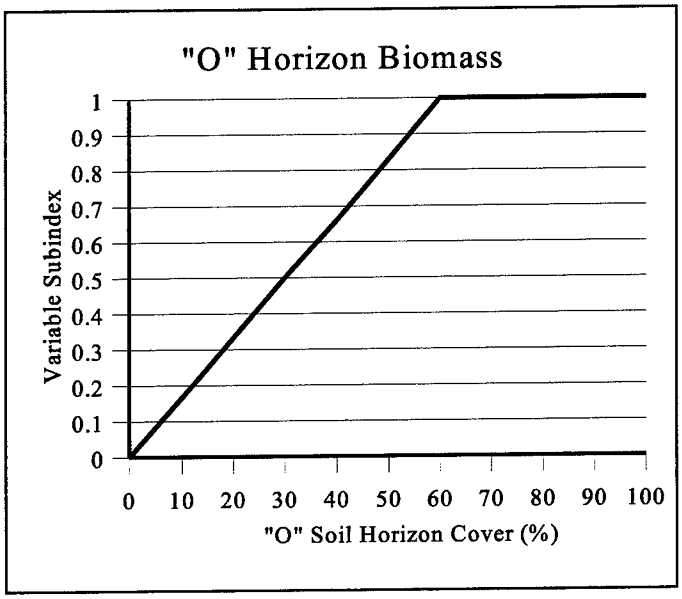


Figure 35. Relationship between "O" soil horizon and functional capacity

In western Kentucky reference wetlands, "O" horizon cover ranged from zero to 100 percent (Appendix D). Based on data from reference standard sites, a variable subindex of 1.0 is assigned when the "O" soil horizon cover is >60 percent (Figure 35). As "O" horizon cover decreases, a linearly decreasing subindex down to zero at zero percent cover is assigned. The rate at which the subindex decreases, and the selection of zero as the subindex endpoint at 100 percent cover, is based on the assumption that the relationship between "O" soil horizon cover and organic carbon export is linear and that a decreasing amount of biomass in the tree, sapling, shrub, and ground vegetation strata of the plant community is reflected in lower percent "O" soil horizon cover. When the "O" soil horizon percent drops to zero, organic carbon export has essentially ceased. These assumptions could be validated using the independent, quantitative measures of function defined above.

Woody debris biomass (V_{WD}). This variable represents the total mass of organic matter contained in woody debris on or near the surface of the ground. Woody debris is defined as down and dead woody stems ≥0.25 in. in diameter that are no longer attached to living plants. Despite its relatively slow turnover rate, woody debris is an important component of food webs and nutrient cycles of temperate terrestrial forests (Harmon, Franklin, and Swanson 1986) and, in the context of this function, contributes to exported organic carbon.

Volume of woody debris per hectare is used to quantify this variable. The procedure for measuring it is described on page 49.

In western Kentucky reference wetlands, the volume of woody debris ranged from zero to 80 m^3/ha (Appendix D). Based on data from reference standard sites, a variable subindex of 1.0 is assigned to sites with woody debris between 20-50 m^3/ha (Figure 36). Below 20 m^3/ha the subindex decreases linearly to 0.0.

This range of values included reference sites that had been converted to agriculture and had little or no woody debris, sites in early stages of succession with low volumes of woody debris, and sites in the middle stages of succession with a volume of woody debris between 10-20 m^3/ha. The decrease in the variable subindex is based on the assumption that lower volumes of woody debris

indicate an inadequate reservoir of organic carbon and an inability to contribute to organic carbon export. Above 50 m^3/ha the subindex decreases linearly to 0.0 at 150 m^3/ha. This is based on the assumption that increasingly higher volumes of woody debris, resulting from logging, will result in abnormally high levels of carbon.

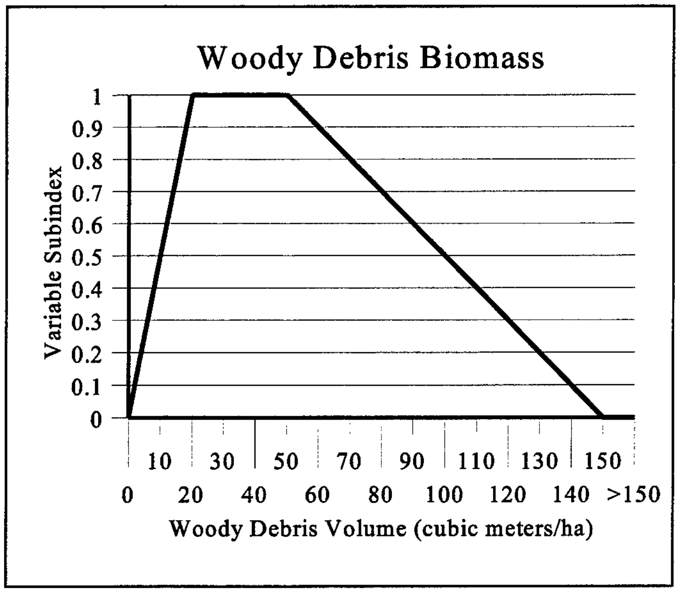


Figure 36. Relationship between woody debris and functional capacity

Functional capacity index

The assessment model for calculating the functional capacity index is as follows:

$$FCI = \left[\left(V_{FREQ} \times V_{SURFCON} \right)^{1/2} \times \left(\frac{V_{OHOR} + V_{WD}}{2} \right) \right]^{1/2} \tag{14}$$

In the first part of this model, the variables V_{FREQ} and $V_{SURFCON}$ reflect whether the mechanisms for exporting organic carbon from the riverine wetland are in place. The two variables are averaged by taking the geometric mean because without flooding, or surface water connections to the channel, organic carbon export could be reduced significantly or cease altogether.

In the second subpart of the equation, the two important sources of dissolved and particulate organic carbon, V_{OHOR} and V_{WD}, are averaged by taking the geometric mean because either subpart is independently capable of significantly reducing the amount of carbon being exported. If the organic matter source of the carbon is not present, carbon export will not occur. Similarly, if the transport vector is absent, carbon export will decrease or cease.

Function 7: Maintain Characteristic Plant Community

Definition

Maintain Characteristic Plant Community is defined as the capacity of a riverine wetland to provide the environment necessary for a characteristic plant community to develop and be maintained. In assessing this function, one must consider both the extant plant community as an indication of current conditions and the physical factors that determine whether or not a characteristic plant community is likely to be maintained in the future. Potential independent, quantitative measures of this function, based on vegetation composition/ abundance, include similarity indices (Ludwig and Reynolds 1988) or ordination axis scores from detrended correspondence

analysis or other multivariate technique (Kent and Coker 1995). A potential independent quantitative measure of this function, based on both vegetation composition and abundance as well as environmental factors, is ordination axis scores from canonical correlation analysis (ter Braak 1994).

Rationale for selecting the function

The ability to maintain a characteristic plant community is important because of the intrinsic value of the plant community and the many attributes and processes of riverine wetlands that are influenced by the plant community. For example, primary productivity, nutrient cycling, and the ability to provide a variety of habitats necessary to maintain local and regional diversity of animals (Harris and Gosselink 1990) are directly influenced by the plant community. In addition, the plant community of a riverine wetland influences the quality of the physical habitat and the biological diversity of adjacent rivers by modifying the quantity and quality of water (Elder 1985; Gosselink, Lee, and Muir 1990) and through the export of carbon (Bilby and Likens 1979; Hawkins, Murphy, and Anderson 1982).

Characteristics and processes that influence the function

A variety of physical and biological factors determine the ability of a riverine wetland to maintain a characteristic plant community. One could simply measure the extant plant community and assume that the wetland was performing the function at a characteristic level if the composition and structure were similar to reference standard wetlands. However, there are potential problems with this approach because of the dynamic nature of plant communities. In particular, woody plants respond relatively slowly to changes in the environment and, consequently, the structure and composition of the plant community may not reflect recent changes in the environmental conditions at a site (Shugart 1987). For example, it can take decades for changes in hydrologic regime to be reflected in the structure and composition of the forest canopy. Herbaceous species respond more quickly to changes in the environment, but using the herbaceous community as an indicator of environmental change is complicated by the fact that herbaceous communities may respond similarly to both natural temporal cycles, such as drought, or permanent changes in environmental conditions resulting from anthropogenic alteration. Thus, relying solely on the extant plant community as an indicator of the capacity of the wetland to perform this function may not accurately reflect current environmental conditions and the capacity of a riverine wetland to maintain a characteristic plant community over the long term.

A rich literature describes the environmental factors that influence the occurrence of plant communities in low gradient, riverine wetlands (Robertson, Weaver, and Cavanaugh 1978; Robertson, McKenzie, and Elliot 1984; Wharton et al. 1982; Robertson 1992; Smith 1996; Messina and Conner 1997; Hodges 1997). The most important factors that have been identified include hydrologic regime and soil type. The problem with using these factors to measure extant conditions is that, because of annual and seasonal variation, it can be difficult to assess their status during a single visit to a wetland site. For example, depending on the season of the year, the water table in many riverine wetlands could range from well below the ground surface to two or more meters above the ground surface. Some indicators, such as bryophyte-lichen lines, integrate conditions over long periods of time, but, like woody vegetation, these indicators often lag or may be insensitive to short-term changes in the condition. Thus, environmental factors alone

may not provide an accurate indication of the capacity of the wetland to perform this function. For these reasons, this function is assessed using variables that reflect both the composition and structure of the extant plant community and environmental factors that influence the capacity of a riverine wetland to maintain a characteristic plant community.

Description of model variables

Tree biomass (V_{TBA}). This variable represents the total mass of organic material per unit area in the tree stratum. Trees are defined as woody stems ≥6 m in height and ≥10 cm in diameter at breast height (dbh) which is 1.4 m above the ground (Bonham 1989). Tree biomass is correlated with forest maturity (Brower and Zar 1984) and, in the context of this function, serves as an indicator of plant community structure.

Tree basal area is used to quantify this variable. Measure it with the procedures described on page 43.

In western Kentucky reference wetlands, tree basal area ranged from 0 to 28 m^2/ha. (Appendix D). Based on the data from reference standard sites supporting mature and fully stocked forests, a variable subindex of 1.0 is assigned when tree basal area is ≥18 m^2/ha (Figure 37). At reference sites that have been cleared or are in middle to early stages of succession, tree basal area is less, and, consequently, a linearly decreasing subindex down to zero at zero tree basal area is assigned. This is based on the assumption that the relationship between tree basal area and the capacity of the riverine wetland to maintain a characteristic plant community is linear. This assumption could be validated with data from a variety of low gradient, riverine wetlands in the Southeast, summarized by Brinson (1990), Christensen (1991), Sharitz and Mitsch (1993), and Messina and Conner (1997), or by the independent, quantitative measures of function identified above.

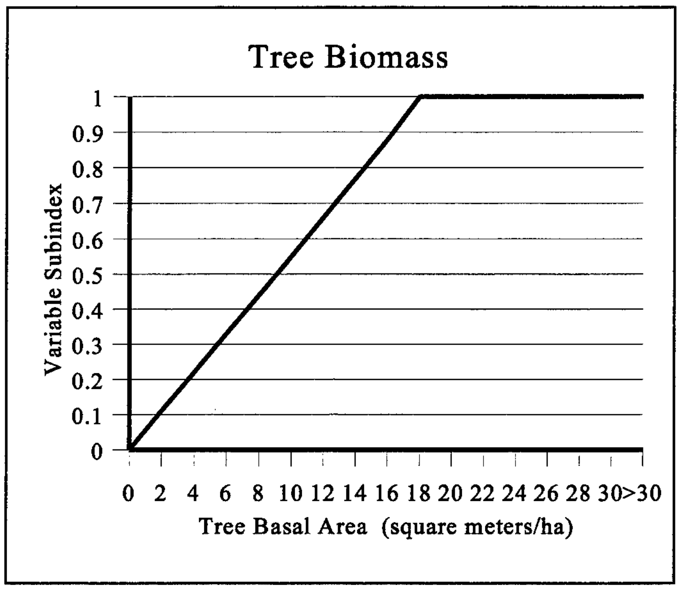


Figure 37. Relationship between tree basal area and functional capacity

Tree density (V_{TDEN}). This variable represents the number of trees per unit area in riverine wetlands. Trees are defined as woody stems ≥6 m in height and ≥10 cm dbh. In most forested systems, tree stem density and basal area increase rapidly during the early successional phase. Thereafter, tree density decreases and the rate at which basal area increases diminishes as the forest reaches mature steady-state conditions (Spurr and Barnes 1980). In the context of this function, tree density serves as an indicator of plant community structure.

The density of tree stems per hectare is used to quantify this variable. Measure it with the following procedure.

(1) Count the number of tree stems in a circular 0.04 ha plot.

(2) If multiple 0.04-ha plots are sampled, average the results from all plots. The number of 0.04-ha plots required to adequately characterize the area being assessed will depend on its size and heterogeneity. Chapter 5, Assessment Protocol, provides guidance for determining the number and layout of sample points and sampling units.

(3) Convert the results to a per hectare basis by multiplying by 25. For example, if the average value from all the sampled plots is 20 stems, then $20 \times 25 = 500$ stems/ha.

(4) Report tree density in stems/hectare.

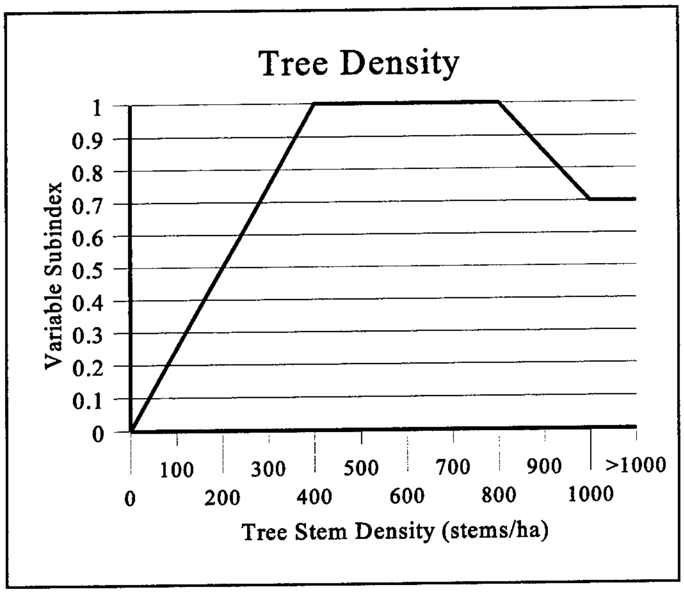


Figure 38. Relationship between tree density and functional capacity

In western Kentucky reference wetlands, tree stem density ranged from zero to 940 stems/ha (Appendix D). Based on the range of values at reference standard sites, a variable subindex of 1.0 is assigned when tree stem densities are between 400 and 800 stems/ha. (Figure 38). At sites that have been cleared for agricultural or other activities where tree stem density is zero, a subindex of zero is assigned. As tree stem densities gradually increase during the early and mid-stages of succession, a linearly increasing subindex is assigned up to 1.0 at 400 stems/ha. As secondary succession continues, stem densities often exceed 800 stems/ha and a linearly decreasing subindex down to 0.7 at $\geq$1000 stems/ha is assigned. This is based on the assumption that the relationship between tree stem density and the capacity of the riverine wetland to maintain a characteristic plant community is linear. This assumption could be validated by analyzing the relationship between tree stem density and the capacity to maintain a characteristic plant community using the data from a variety of low gradient riverine wetlands in the Southeast, summarized by Brinson (1990), Christensen (1991), Sharitz and Mitsch (1993), and Messina and Conner (1997).

Plant species composition (V_{COMP}). Plant species composition represents the diversity of plants in riverine wetlands. In general, healthy, mature forest stands support higher species diversity in all strata than do younger stands due to the greater overall complexity. Ideally, plant species composition would be determined with intensive sampling of woody and herbaceous species in all vegetation strata. Unfortunately, the time and taxonomic expertise required to

accomplish this are not available in the context of rapid assessment. Thus, the focus here is on the dominant species in each vegetation stratum.

Percent concurrence with the dominant species in each vegetation stratum is used to quantify this variable. Measure it with the following procedure.

(1) Identify the dominant species in the canopy, understory vegetation, and ground vegetation strata using the 50/20 rule.[1] Use tree basal area to determine abundance in the canopy stratum, understory vegetation density to determine abundance in the understory stratum, and ground vegetation cover to determine abundance in the ground vegetation stratum. To apply the 50/20 rule, rank species from each stratum in descending order of abundance. Identify dominants by summing the relative abundances beginning with the most abundant species in descending order until 50 percent is exceeded. Additional species with ≥20 percent relative abundance should also be considered as dominants. Accurate species identification is critical for determining the dominant species in each plot. Sampling during the dormant season may require a high degree of proficiency in identifying tree bark or dead plant parts. Users who do not feel confident in identifying plant species in all strata should get help with plant identification.

(2) For each vegetation stratum, calculate percent concurrence by comparing the list of dominant plant species from each stratum to the list of dominant species for each stratum in reference standard wetlands (Table 13). For example, if all the dominants from the area being assessed occur on the list of dominants from reference standard wetlands, then there is 100 percent concurrence. If 3 of the 5 dominant species of trees from the area being assessed occur on the list, then there is 60 percent concurrence.

(3) Average the percent concurrence from all three strata.

(4) Report concurrence of species dominants across all vegetation as a percent.

In western Kentucky reference wetlands, percent concurrence with dominant species ranged from zero to 100 percent (Appendix D). Based on the data from reference standard sites supporting mature and fully stocked forests, a variable subindex of 1.0 is assigned when concurrence with dominant species is 100 percent (Figure 39). As percent concurrence decreases, a linearly decreasing subindex down to zero is assigned based on the assumption that the relationship between plant species composition and the capacity of the riverine wetland to maintain a characteristic plant community is linear.

Overbank flood frequency (V_{FREQ}). This variable represents the frequency at which water from a stream overtops its banks (i.e., exceeds channel-full discharge) and inundates riverine wetlands on the floodplain. Overbank flood frequency is a manifestation of current conditions in the watershed and channel at the spatial scale of the riverine wetland. In the context of this function, overbank flood frequency serves as an indication that a characteristic hydrologic regime to which the plant community is adapted is in place.

Recurrence interval in years is used to quantify this variable. The procedure for measuring this variable is described on page 24.

---

[1] Memorandum, 6 March 1992, Office, Chief of Engineers, Clarification of Use of the 1987 Delineation Manual.

Table 13
Dominant Species by Vegetation Strata in Reference Standard Sites in Western Kentucky

Tree	Shrub/Sapling	Ground Cover
Acer rubrum	*Acer rubrum*	*Arundinaria gigantea*
Betula nigra	*Betula nigra*	*Aster* sp.
Carya laciniosa	*Carya laciniosa*	*Boehmaria cylindrica*
Celtis laviegata	*Carpinus caroliniana*	*Campsis radicans*
Fraxinus pennsylvanica	*Celtis laviegata*	*Carex squarosa*
Liquidambar styraciflua	*Celtis occidentalis*	*Eragrostis alba*
Quercus pagodifolia	*Fraxinus pennsylvanica*	*Glyceria striata*
Quercus phellos	*Ilex decidua*	*Hypericum* sp.
Quercus lyrata	*Liquidambar styraciflua*	*Impatiens capensis*
Quercus imbricaria	*Nyssa sylvatica*	*Panicum* sp.
Quercus michauxii	*Quercus imbricaria*	*Parthenocissus quinquefolia*
Quercus stellata	*Quercus lyrata*	*Pilea pumila*
Quercus palustris	*Quercus phellos*	*Quercus phellos*
Salix nigra	*Quercus palustris*	*Salix nigra*
	Quercus pagodifolia	*Sauraurus cernuus*
	Quercus stellata	*Smilacina racemosa*
	Platanus occidentalis	*Smilax rotundifolia*
	Salix nigra	*Sparganium* sp.
	Ulmus americana	*Toxicodendron radicans*

In western Kentucky reference wetlands, using regional dimensionless curves, recurrence interval ranged from 1-25 years (Appendix D). Based on the range of values from reference standard sites, a variable subindex of 1.0 is assigned to recurrence intervals ≤1.0 year (Figure 40). Longer recurrence intervals are assigned a linearly decreasing subindex to 0.1 at a recurrence interval of 10 years. This is based on the assumption that where entrenchment, channelization, or levees effectively increase the depth of the stream channel, a greater discharge is required to overtop the bank and inundate the riverine wetland. Since greater discharges occur less frequently, the volume of surface water that inundates riverine wetlands is less than what characteristically occurs at reference standard sites. The rationale for the rate at which the subindex drops to 0.1 (i.e., 1.0 to 0.1) is based on the assumption that, as frequency increases, the inundation of the wetland by annual peak discharges decreases to one-tenth the frequency over a period of 10 years under reference standard conditions.

Recurrence intervals >10 years are assigned a subindex of 0.1. This is based on the assumption that, even at longer recurrence intervals, riverine wetlands do flood, albeit infrequently. Again, conceptual arguments can be made for dropping the subindex to zero, but it is difficult to deter-mine at what point an increasing recurrence interval begins to significantly influence the ecologi-cal processes linked to overbank flooding.

Water table depth (V_{WTD}). This variable represents the depth to seasonal high water table in the riverine wetland. In the context of this function, this variable indicates that plant communities adapted to the characteristic seasonal high water table will develop and be maintained.

Depth to the seasonal high water table is used to quantify this variable. The procedure for measuring this variable is described on page 55.

In western Kentucky reference wetlands, the depth to seasonal high water table ranged from zero to 18 in. below the surface (Appendix D). Based on the range of values from reference standard sites, a variable subindex of 1.0 was assigned to seasonal high water table "depths" between zero (i.e., ground surface) and 6 in. below the ground (Figure 41). As the depth to the seasonal high water table increases (i.e., is farther below the surface of the ground) the subindex decreases decreases linearly to zero at a depth of 24 in. This is based on the assumption that the capacity of the riverine wetland to maintain the degree of soil saturation required for characteristic biogeochemical processes and plant and animal communities is dependent on maintaining a characteristic seasonal high water table near or above the surface of the ground.

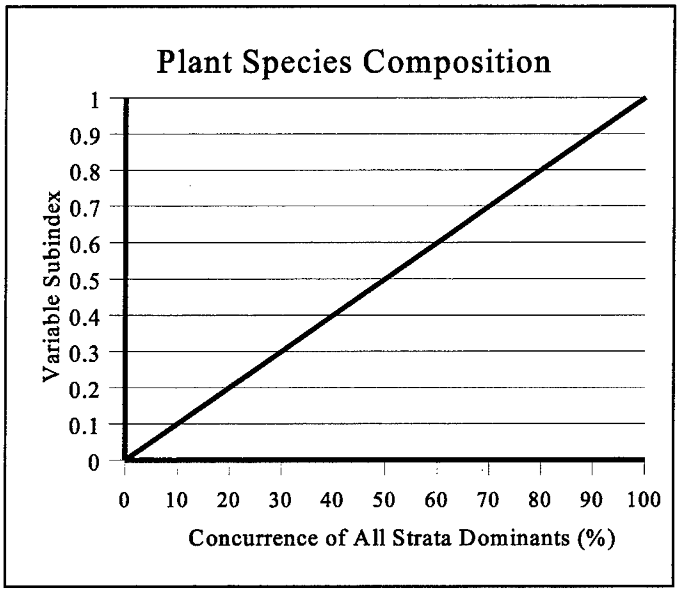


Figure 39. Relationship between percent concurrence of strata dominants and functional capacity

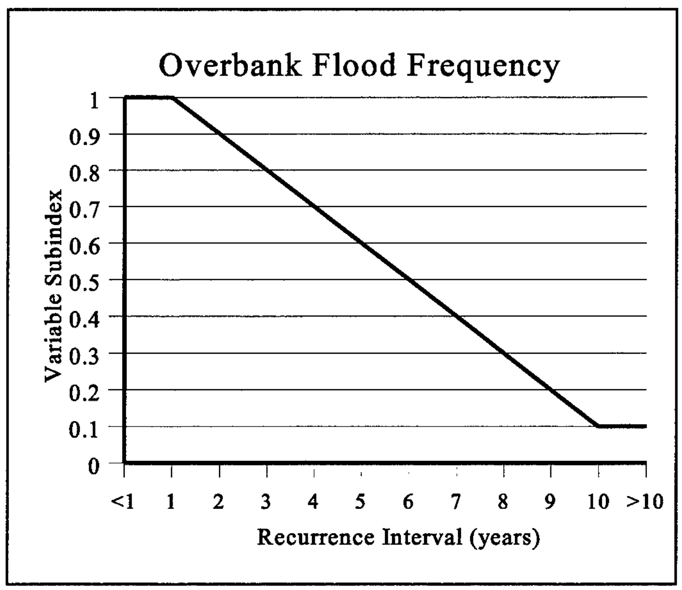


Figure 40. Relationship between recurrence interval and functional capacity

Soil integrity ($V_{SOILINT}$). This variable is defined as the integrity of the soils within the area being assessed. Soil integrity is defined as the degree to which a soil approximates the natural undisturbed soil originally found at the site with respect to structure, horizonation, organic matter content, and biological activity. Soil is the medium on which the plant community develops and is maintained. Altering the properties of soil through anthropogenic activities (e.g., fill, excavation, plowing, compaction) has the potential to affect the structure and composition of the plant community.

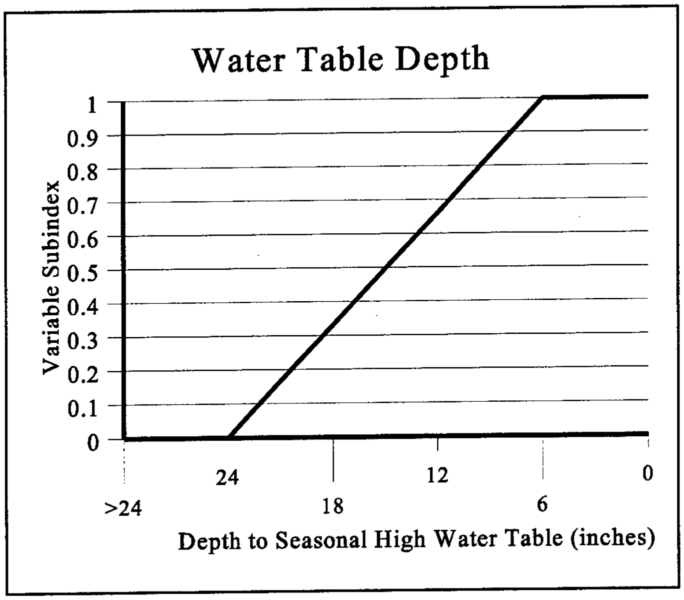


Figure 41. Relationship between depth to seasonal high water table and functional capacity

It is difficult in a rapid assessment context to assess soil integrity for two reasons. First, there are a variety of soil properties contributing to integrity that must be measured (i.e., structure, horizonation, texture, bulk density). Second the spatial variability of soils within riverine wetlands makes it difficult to collect the number of samples necessary to adequately characterize a site. Therefore, the approach used here is to assume that soil integrity exists where evidence of alteration is lacking. Stated another way, if the soils in the assessment area do not exhibit any of the characteristics associated with alteration, it is assumed that soils are similar to those occurring in the reference standard wetlands and have the potential to support a characteristic plant community.

The field measure of this variable is the proportion of the assessment area with altered soils. Measure it with the following procedure.

(1) Determine if any of the soils in the area being assessed have been altered. In particular, look for alteration to a normal soil profile. For example, absence of an "A" horizon, presence of fill material, or other types of impact that significantly alter soil integrity.

(2) If no altered soils exist, assign the variable subindex a value of 1.0. This indicates that all of the soils in the assessment area are similar to soils in reference standard sites.

(3) If altered soils exist, determine what percent of the assessment area has soils that have been altered.

(4) Report the percent of the assessment area with altered soils.

In western Kentucky reference wetlands, the percent of area with altered soils ranged from zero to 100 percent (Appendix D). Based on the values from reference standard sites, a variable subindex of 1.0 was assigned when the percent of area with altered soils was zero (Figure 42). As the percentage of area with altered soils increases, a linearly decreasing subindex down to zero at 100 percent alteration is assigned. This is based on the assumption that, as the percentage of altered soils increases, the capacity of the soil to support a characteristic plant community decreases linearly.

Functional capacity index

The assessment model for deriving the functional capacity index is as follows:

$$FCI = \left[\frac{\left(\frac{V_{TBA} + V_{TDEN}}{2}\right) + V_{COMP}}{2} \times \frac{F_{SOILINT} + V_{FREQ} + V_{WTD}}{3} \right]^{1/2} \quad (15)$$

In the first part of the model, V_{TBA} and V_{TDEN} are averaged to provide an indication of the structural maturity of the stand. This result is then averaged with V_{COMP} to provide an indication of how similar the plant community is to reference standard conditions in terms of structure and species composition. For example, a stand with low basal area (6 m^2/ha) and high tree density (800-1000/ha) is indicative of an immature stand and would receive a lower FCI. A stand with higher basal area (>18 m^2/ha) and lower density of trees (500 trees/ha) represents a relatively mature stand and would receive a higher FCI.

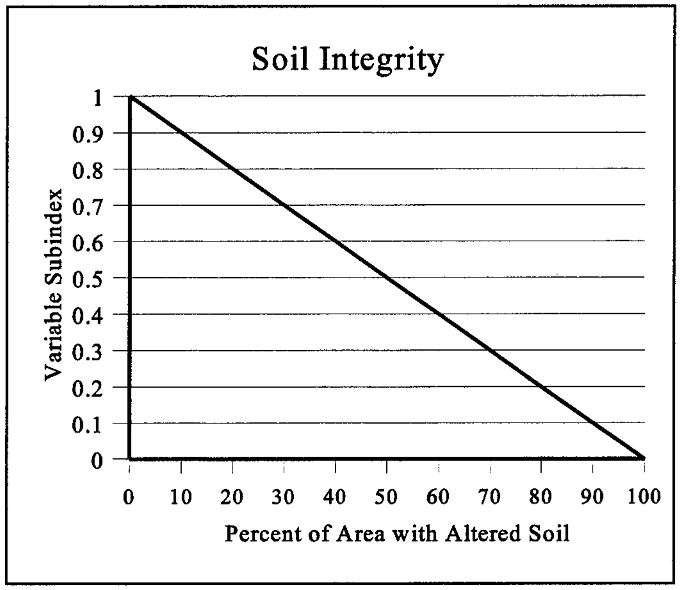


Figure 42. Relationship between soil integrity and functional capacity

In the second part of the equation, the abiotic factors that influence the current or future composition and structure of the plant community are considered. The V_{FREQ}, V_{WTD}, and $V_{SOILINT}$ variables, which are partially compensatory and assumed to be equal and independent, are averaged using an arithmetic mean.

The two parts of the equation are also considered to be independent and are averaged using a geometric mean based on the assumption that both structure and species composition and abiotic factors contribute equally to the maintenance of a characteristic plant community. If the subindices for the variables in either part of the model decrease, there will be a reduction in the FCI.

Function 8: Provide Habitat for Wildlife

Definition

Provide Habitat for Wildlife is defined as the ability of a riverine wetland to support the wildlife species that utilize riverine wetlands during some part of their life cycles. The focus of attention, however, is on the avifauna component of habitat based on the assumption that, if conditions are appropriate to support the full complement of avian species found in reference standard

wetlands, the requirements of other animal groups (e.g., mammals, reptiles, and amphibians) will be met. A potential independent, quantitative measure of this function is a similarity index calculated from species composition and abundance (Odum 1950, Sorenson 1948).

Rationale for selecting the function

Riverine floodplains and the wetlands associated with them are used extensively by terrestrial, semiaquatic, and aquatic animals to complete their life histories. The performance of this function ensures habitat for a diversity of vertebrate organisms, contributes to secondary production, maintains complex trophic interactions, provides access to and from wetlands for completion of aquatic species life cycles. Performance of this function also provides refugia and habitat for wide-ranging or migratory birds and conduits for dispersal of species to other areas. Habitat requirements for individual species and even groups of similar species sometimes are highly specialized; however, most wildlife and fish species found in riverine floodplains depend on certain common characteristics such as hydroperiod, topography, forest composition and structure, and proximity to other habitats.

Characteristics and processes that influence the function

In riverine, low gradient wetlands, hydrology in the form of flooding is one of the major factors influencing wildlife habitat quality. Flooding helps sustain the forest community upon which most of the fauna depend and provides the vector for aquatic organisms to access the wetland. Many of these aquatic organisms are utilized as a food source by birds, mammals, reptiles, and amphibians. Access to the floodplain may be direct or through surface channels. Natural or manmade levees may restrict surface connections to wetlands during low flood years; however, extensive areas of a river corridor may be flooded during significant rainfall or snowmelt events, allowing unrestricted access to and across the floodplain.

Low gradient, riverine wetlands are extremely important habitats to numerous fish species. Wharton et al. (1982) provided an overview of fish use of bottomland hardwoods in the Piedmont and eastern Coastal Plain and stated that at least 20 families and up to 53 species of fish use various portions of the floodplain for foraging and spawning. The Ictaluridae (catfish), Centrarchidae (sunfish), Lepisosteidae (gar), Percidae (perch), and Catostomidae (sucker) families were the most abundant. Baker and Killgore (1994) studied larval and adult fishes in the Cache River drainage in Arkansas and found even more species. They identified 56 different species in the river system and speculated that the actual number exceeds 60. The Percidae, Cyprinidae (minnow), and Aphredoderidae (monotypic) were the dominants.

Most of the species identified by Baker and Killgore (1994) exploit floodplain habitats at some time during the year; many for spawning and rearing. The authors investigated differential habitat use by larval and juvenile fishes and found that the oak-dominated habitats which constituted the bulk of the Cache River floodplain contained significantly more individuals than either oxbows or the channel itself. A few (10) species were most common in the oxbows; relatively few larval fish were found in the channel. These findings highlight the importance of floodplain habitats to the ichthyofauna of low gradient river systems such as the Cache.

Overbank flooding is necessary in affording access to riverine wetlands by anadromous or adfluvial fishes that use floodplain habitats to complete portions of their life histories such as spawning and rearing (Lambou 1990, Baker and Killgore 1994). The temporal periodicity and magnitude of flooding may have direct bearing on strengths of year classes. Lambou (1959) suggested that fish depend on annual fluctuations in water level to limit intra- and interspecific competition for food, space, and spawning grounds. Baker and Killgore (1994) found that the larval fish catch was much higher in a year with extensive, continuous flooding than in a year when flooding was less extensive and sporadic. Thus, regular overbank flooding and connectivity through channels are critical components to consider relative to a site-specific evaluation of fish habitat.

In addition to flooding itself, the complex environments of floodplains are of significance to fishes. Wharton et al. (1982) listed numerous examples of fish species being associated with certain portions of the floodplain. Baker, Killgore, and Kasul (1991) noted that the different microhabitats on the floodplain typically supported different fish assemblages from those of the channel. Baker and Killgore (1994) stated that "the structurally complex environment of irregularly flooded oak-hickory forests provide optimum habitat for many wetland fishes."

Riverine floodplains often contain a mosaic of habitat types that vary temporally and spatially. The pattern of types present in an area at a given time is one of the major determinants of its capacity to provide habitat for wildlife. In unaltered riparian areas, the floodplain often is comprised of topographically distinct features that reflect the hydrogeological processes that have occurred there (Mitsch and Gosselink 1993). Flats, ridges, swales, and oxbows support distinctive plant communities or "zones" (Wharton et al. 1982). In addition to the variability resulting from hydrogeological processes, forested floodplain wetlands vary in terms of the successional stages present on the landscape. Even in unharvested forested wetlands, considerable variability may occur as a result of natural processes. For example, windthrow, herbivory, diseases, and insect outbreaks all affect the forest community and are capable of altering both age and species composition (Wharton et al. 1982).

Several authors including Fredrickson (1978) and Wharton et al. (1982) have documented that mature hardwood forests associated with low gradient, riverine wetlands support a rich diversity of animal life. In fact, several studies have shown that both bird species richness and bird species diversity are higher in such riparian habitats than in many adjacent habitats (Dickson 1978, Stauffer and Best 1980, Szaro 1980). Dickson (1978) found breeding bird densities in riparian zones to be 2 to 4 times higher than in upland habitats in the same area.

The principal reason that riverine forested wetlands support such a high diversity of terrestrial and semiaquatic wildlife is that they are floristically and hydrologically complex (Wharton et al. 1982) and (in mature systems) structurally diverse in the vertical plane (Hunter 1990). This structural diversity (layering) provides a myriad of habitat conditions for animals and allows numerous species to coexist in the same area (Schoener 1986). For example, some species of birds utilize various parts of the forest canopy whereas others are associated with the understory (Cody 1985, Wakeley and Roberts 1996). MacArthur and MacArthur (1961) documented the positive relationship between the vertical distribution of foliage (termed foliage height diversity) and avian diversity, and other researchers have since corroborated their findings. Hunter (1990) provided a good overview of the importance of structure to wildlife and noted examples of other faunal groups (mammals, reptiles, and insects) that also partition resources in a similar manner.

The composition of the plant community found in the wetland is also an important factor relative to utilization by some wildlife species. These floodplain forests commonly are extremely diverse and may contain hundreds of species. Wharton et al. (1982) listed over 50 species of trees alone, but members of the genus *Quercus* (the oaks) commonly are of overriding significance to wildlife. This significance is due to their producing acorns (sometimes called mast) which are among the most important items in the diet of many wildlife species. Some of the animals that depend on mast include the gray squirrel (*Sciurus carolinensis*), eastern wild turkey (*Meleagris gallopavo*), and wood duck (*Aix sponsa*) (U.S. Forest Service 1980). Reinecke et al. (1989) noted that acorns make up the bulk of the diet of wood ducks during most years and of mallards (*Anas platyrhynchos*) during years of good mast production. Because these two species are the most abundant ducks in the Mississippi Alluvial Valley (Reinecke et al. 1989), having a significant number of oaks in the community, especially those from the red oak group, is very important. While oaks provide the bulk of the hard mast utilized by wildlife in southern forested wetlands, hickories (*Carya* spp.) and American beech (*Fagus grandifolia*) are very important also, especially to squirrels (Allen 1987).

Sometimes animals have very specific habitat needs relative to the overall forest community. For example, Wharton et al. (1982) listed numerous vertebrate and invertebrate species found in the different zones of the bottomland hardwood community that are closely associated with the litter layer, either using it for food or for cover. Litter provides ideal habitat for small, secretive animals such as salamanders (Johnson 1987) and has a distinctive invertebrate fauna (Wharton et al. 1982) that is vital to some of the more visible members of the community. For example, wood ducks are known to forage extensively on macroinvertebrates found in the floodplain prior to egg laying. Similarly, mallards heavily utilize the abundant litter invertebrate populations associated with flooded bottomland forests during winter (Batema, Henderson, and Fredrickson 1985). Generally, the higher portions of the floodplain (Zones IV and V) have the highest amounts of litter (Wharton et al. 1982).

Logs and other woody debris provide cover and a moist environment for a myriad of species including invertebrates, small mammals, reptiles, and amphibians (Hunter 1990). Animals found in forested wetlands use logs as resting sites, feeding platforms, and as sources of food (Harmon, Franklin, and Swanson 1986). Logs provide cover, runways, and feeding sites for small mammals (Loeb 1993). It was noted that at least 55 of 81 species of mammals in the Southeast use downed woody debris and that it may be a critical habitat feature for some. Reptiles and amphibians like-wise use logs and other coarse woody debris extensively. Whiles and Grubaugh (1993) summarized the literature on the use of woody debris by herptofauna and listed reproduction, feeding, thermoregulation, and protection from desiccation as important functions associated with coarse woody debris. Some specific examples of use of logs by species in riverine wetlands include nesting sites for marbled salamanders (*Ambystoma opaceum*) and basking sites for watersnakes in the genus *Nerodia*. To further illustrate how significant some of these small-scale features may be, Elton (1968) estimated that in England nearly 1,000 animal species rely on dead and dying wood for food or cover. Such a comprehensive listing is specifically lacking for southern riverine wetlands; however, Wharton et al. (1982) listed numerous species from various taxonomic groups that are associated with litter, logs, and crayfish burrows in bottomland hardwood forests.

Standing dead trees are one of the most important of the special habitat features used by many species. Snags are used by numerous birds, and several are dependent on them for their existence (Scott et al. 1977). Stauffer and Best (1980) found that most cavity-nesting birds,

particularly the primary cavity nesters such as woodpeckers, preferred snags over live trees. In southern riverine forests, some of the avian species using snags (in addition to the woodpeckers) include the wood duck, Carolina chickadee (*Parus carolinensis*), and prothonotary warbler (*Pronotaria citrea*). Mammals found in forested wetlands that are dependent on snags to an extent include the big brown bat (*Eptesicus fuscus*), gray squirrel, and raccoon (*Procyon lotor*) (Howard and Allen 1989). Hunter (1990) stated that although birds dominate the list of cavity users, most species of forest-dwelling mammals, reptiles, and amphibians, along with numerous invertebrates, seek shelter in cavities, at least occasionally. The type and abundance of snags needed vary among species. For example, woodpeckers can excavate cavities in hard snags while chickadees and nuthatches (*Sitta* spp.) can do so only in snags in which the wood is very soft (Hunter 1990). Thus, having a forest with snags in several different stages of decay is desirable for supporting all potential users.

Site-specific topography is one of the most important physical factors affecting use by many wildlife species. For example, depressions on a floodplain pond water, sometimes for relatively long periods following rainfall or overflow events. These ponded areas provide excellent breeding habitat for a variety of semiaquatic organisms such as salamanders and frogs (Wharton et al. 1982, Johnson 1987). Breeding sites without predatory fish populations are very important for some species such as the marbled and mole salamanders (*Ambystoma opacum* and *A. talpoideum*), gray treefrog (*Hyla versicolor*), and woodfrog (*Rana sylvatica*) (Johnson 1987). Also important are sites that retain water for a period sufficient for eggs to hatch or larvae to develop, generally 2-3 months for anurans (Duellman and Trueb 1986), thus shallow depressions such as those characterized by *Quercus lyrata* and *Carya aquatica* may be especially important. Distribution of frogs and salamanders varies across the floodplain and is described by Wharton et al. (1982).

Slightly higher areas which do not flood are important to ground-dwelling species that cannot tolerate prolonged inundation. Wharton et al. (1982) stated that old levee ridges are extremely important in the life of many floodplain species, because they provide winter hibernacula and refuge areas during periods of high water. Similarly, Tinkle (1959) found that levees were used extensively by many reptiles and amphibians as egg-laying areas. Keiser (1976) noted that the marbled salamander (*Ambystoma opacum*) does not occur in areas that flood for long durations. Presumably, small mammals that utilize the floodplains of southern forested wetlands (e.g., the deer mouse (*Peromyscus maniculatus*), golden mouse (*Ochrotomys nuttalli*), short-tailed shrew (*Blarina brevicauda*), and southeastern shrew (*Sorex longirostris*)) (Wharton et al. 1982) also benefit from the presence of higher areas in the floodplain. Wharton et al. (1982) noted that the latter two species retreat to higher ground during periods of inundation. Other mammals that probably use the higher ridges during flood events include the swamp rabbit (*Sylvilagus aquaticus*), mink (*Mustella vison*), and raccoon (*Procyon lotor*).

It is assumed that the more variable the surface of the wetland is, the greater the variety of wildlife species that will utilize it. Topographic complexity results in plant community complexity, and this, along with ponded depressions of varying sizes and depths, greatly enhances the ability of the wetland to support the differing needs of a high diversity of aquatic, semiaquatic, and terrestrial wildlife species.

Landscape-level features such as forest patch size, shape, connectivity, and surrounding land use are also important attributes that affect the wildlife community (Hunter 1990; Morrison, Marcot, and Mannan 1992). Many of the concepts regarding these landscape features originated

with MacArthur and Wilson's (1967) theory of island biogeography which states that immigration and extinction rates that control population size are themselves influenced by island size and spatial considerations. In general, larger islands that are near a source of colonists support larger and more stable populations. It is believed that reduction and fragmentation of forest habitat, coupled with changes in the remaining habitat, resulted in the loss of the ivory-billed woodpecker (*Campephilus principalis*), Bachman's warbler (*Vermivora bachmanii*), and the red wolf *(Canis rufus*) and severe declines in the black bear (U*rsus americanus*) and Florida panther (*Puma concolor*).

Recent studies that have investigated whether this size area relationship is true in forested habitats (some have been forested wetlands) relative to bird populations have yielded mixed results. For example, Stauffer and Best (1980); Howe (1984); Askins, Philbrick, and Sugeno (1987); Keller, Robbins, and Hatfield (1993); and Kilgo et al. (1997) found that bird species richness increases with forest area (generally through the addition of edge species). Other studies have concluded that there is no relationship or even a negative relationship between bird species richness and area (Blake and Karr 1984; Lynch and Whigham 1984; Sallabanks, Walters, and Collazo 1998).

While the effects of patch size alone on overall bird species richness need additional clarification, the negative effects of forest fragmentation on some species of birds have been well documented (Finch 1991). These species, referred to as "forest interior" species, apparently respond negatively to unfavorable environmental conditions or biotic interactions in fragmented forests (Ambuel and Temple 1983). Nests near forest edges have been found to experience higher rates of nest predation (Wilcove 1985, Yahner and Scott 1988) and parasitism by brown-headed cowbirds (Brittingham and Temple 1983). Thus, as forests become fragmented into smaller and smaller blocks, the amount of "edge" habitat relative to the amount of "interior" habitat increases, leading to declines of species sensitive to such changes. At what point fragmentation effects begin to be realized has yet to be defined. Some studies suggest that most predation and brood parasitism occur within about 100 m of the forest edge (Temple 1986), although recent work in a forested riparian corridor in Arkansas showed that avian parasites and predators penetrate deeply into even large forest tracts (Wakeley and Roberts 1996).

The size area needed to accommodate all the species typically associated with unfragmented blocks of forested wetlands in the region can only be approximated. Except for a few wide-ranging carnivores, most of the concern about fragmentation effects have involved birds; thus, they are the best group to serve as a guide for developing standards for the entire wetland faunal community. The number of breeding bird species detected by Wakeley and Roberts (1996) in an intact riparian corridor (N = 43) was similar to that found by Hamel (1989) in the Congaree Swamp , South Carolina (N = 41 in old growth bottomland hardwoods and 47 in selectively harvested bottomland hardwoods). These richness values probably approach the maximum that can be expected in large, relatively unfragmented southern forested wetlands. Nineteen species considered to be area sensitive (Temple 1986; Robbins, Dawson, and Dowell 1989) were present in the Arkansas study area, although two species expected to be present, the cerulean warbler (*Dendroica cerulea*) and Swainson's warbler (*Limnothlypis swainsoni*), were absent. This suggests that the 2-3 km width of the forested corridor, in conjunction with more than twice that distance linearly, while sufficient to support most area sensitive species, still was too small for some with larger area requirements.

When the maintenance of breeding populations is considered, in addition to simply supporting or not supporting individuals of a species, the size of the area needed may be magnified significantly. For example, Mueller, Loesch, and Twedt (1995) identified three groups of birds that breed in the Mississippi Alluvial Valley with (presumably) similar needs relative to patch size. They suggested that to sustain source breeding populations of individual species within the 3 groups, that 44 patches of 4,000 - 8,000 ha, 18 patches of 8,000 - 40,000 ha, and 12 patches larger than 40,000 ha are needed. Species such as the Swainson's warbler are in the first group; more sensitive species such as the cerulean warbler are in the second group; and those with very large home ranges (e.g., raptors such as the red-shouldered hawk (*Buteo lineatus*)) are in the third group.

The land-use surrounding a tract of forest also has a major effect on avian populations. Recent studies (Thompson et al. 1992; Welsh and Healy 1993; Sallabanks, Walters, and Collazo 1998; Robinson et al. 1995) suggest that bird populations respond to fragmentation differently in forest dominated landscapes than in those in which the bulk of the forests have been permanently lost to agriculture or urbanization. Generally, cowbird (*Molothrus ater*) populations are higher in fragmented landscapes where there is a mixture of feeding habitats (agricultural and suburban lands) and breeding habitats (forests and grasslands) (Robinson et al. 1993, 1995). In such areas, even large blocks of habitat may lack the secure "interior" conditions needed by some species (Robinson et al. 1995). Formerly, cowbirds were thought to penetrate only relatively short distances (e.g., 300 m) (Temple and Cary 1988) into forests, but recent studies (Wakeley and Roberts 1996, Thompson et al. 1998) found cowbirds much farther from the nearest edge. Both studies were conducted in areas in which the landscape matrix was agricultural. Robinson et al. (1995) reported that predation rates also were much higher in the most fragmented landscapes and suggested that landscapes that are largely forested may be necessary to provide colonists to maintain populations of some species in highly fragmented areas. Robinson (1996) suggested that the area within a 9.6-km radius of a study site (approximately 30,300 ha) was an appropriate estimator. Further, he noted that as the percentage of the landscape that is forested increases above 70 percent (approximately), the size of the forest blocks within that landscape becomes less significant to bird populations. Thus, in more open landscapes, block sizes need to be larger than in mostly forested ones.

In landscapes that are fragmented, corridors have been suggested as a means of ameliorating many of the anticipated negative effects of fragmentation (Harris 1985, Noss and Harris 1986). Intuitively, corridors should be beneficial to a range of species; however, Simberloff et al. (1992) argued that many of the proposed benefits of corridors (increased migration with a subsequent reduction in extinction) have never been substantiated. Part of the confusion surrounding corridors is the scale at which they are viewed. Harris (1988) advocated an extensive network of corridors in Florida to connect national forests, refuges, and other large blocks of land. Some of these corridors would have to be >4 km wide. This concept is very different from connecting a small isolated block of habitat to another block by means of a narrow (e.g.,<100 m) strip of habitat. Hunter (1990) concluded that the value of corridors was species-specific, but for some animals, corridors probably would be beneficial.

In bottomland forest communities, probably the most significant habitat connection to many species is between the wetland and a block of similar habitat in the adjacent uplands. Such a connection is invaluable for allowing terrestrial species, especially, to move from the floodplain during periods of very high water (Wharton et al. 1982). In general, connections between different wetland types, and between uplands and wetlands, help maintain higher animal and

plant diversity across the landscape than if habitats were more isolated from one another (Sedell et al. 1990).

Although it is impossible to describe the optimum size of forested riverine wetlands, relative to fish and wildlife habitat, or at what point landscape factors begin to degrade habitat quality, it is possible to generalize about these concepts. It can be assumed that large tracts with a high ratio of interior to edge habitat are preferred over smaller ones with little interior habitat. Also, it can be assumed that other types of "natural" habitat, including upland areas, are important, especially to wildlife, and the closer together these areas are, the greater the diversity of wildlife utilizing them will be. Generally, the continuity of vegetation, connectivity of specific vegetation types, the presence and scope of corridors between upland/wetland habitats, and corridors among wetlands all have direct bearing on the movement and behavior of animals that use wetlands.

Description of site scale model variables

This function is community based and evaluates wildlife habitat by assessing site specific and landscape level variables which focus on the avifauna. The model contains 11 variables which represent 3 major components of wildlife habitat (hydrology, plant community, and landscape) which are related to the richness and abundance of birds in the riverine low gradient subclass. The assumption in this model is that if habitat requirements for birds are met, then a broad range of other wildlife species habitat requirements will also be met. For instance, downed logs and litter are required for towhees, wrens, and Kentucky warblers. These habitat components are also utilized by small mammals and herptofauna for cover and feeding. The following variables are grouped by the three major habitat components listed above for the purpose of organization and clarity.

Overbank flood frequency (V_{FREQ}). This variable represents the frequency at which water from a stream overtops its banks (i.e., exceeds channel-full discharge) and inundates riverine wetlands on the floodplain. Overbank flooding of the proper frequency, depth, and duration maintains a characteristic plant community which in turn influences fish and wildlife richness and diversity. Certain fish species depend on overbank events during the appropriate season to allow access to the floodplain for foraging and spawning. Frequent flooding, even for short durations, keeps soil and litter moist and provides pools of surface water in depressions that serve as important sources of water for wildlife and are critical for reproduction in some invertebrates and amphibians.

Recurrence interval in years is used to quantify this variable. The procedure for measuring this variable is described on page 24.

In western Kentucky reference wetlands, using regional dimensionless curves, recurrence interval ranged from 1-25 years (Appendix D). Based on the range of values from reference standard sites, a variable subindex of 1.0 is assigned to recurrence intervals $\leq$1.0 year (Figure 43). Longer recurrence intervals are assigned a linearly decreasing subindex to 0.1 at a recurrence interval of 10 years. This is based on the assumption that where entrenchment, channelization, or levees effectively increase the depth of the stream channel, a greater discharge is required to overtop the bank and inundate the riverine wetland. The rationale for the rate at which the subindex drops to 0.1 (i.e., 1.0 to 0.1) is based on the assumption that, as frequency

increases, the capacity of the wetland to store annual peak discharges decreases to one-tenth the amount of water stored over a period of 10 years under reference standard conditions. Model validation will help to define the actual nature of this relationship. Recurrence intervals >10 years are assigned a subindex of 0.1. This is based on the assumption that, even at longer recurrence intervals, floodplain forests provide some habitat for wildlife species.

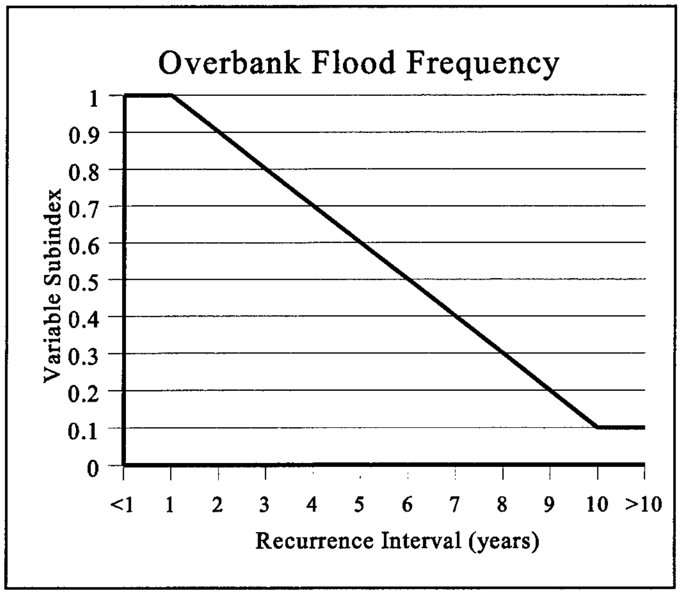


Figure 43. Relationship between recurrence interval and functional capacity

Macrotopographic features (**V_{MACRO}**). This variable represents the occurrence of macrotopographic features in the riverine wetland. Macrotopographic features are defined as floodplain topographic features large enough to be detected on 1:2400 scale aerial photographs, greater than 1 m in depth, and capable of holding water for extended periods of time. Normally these features lack outlets and thus trap surface water on a semipermanent basis. Abandoned channels are typical macrotopographic features in western Kentucky riverine wetlands. In the context of this function, the surface water impounded by macrotopographic features provides essential habitat to a variety of avifaunal species when floodwater recedes.

Macrotopographic relief is a large-scale feature of most floodplains. As such, the area in which this variable is assessed must be large enough to represent the floodplain. Therefore, 1 km ^{2} was chosen as the appropriate scale of measure. If the area being assessed is greater than 1 km^2, the percentage of the area that consists of macrotopographic features is used to quantify this variable. Measure it with the procedure outlined under Alternative 1 if the area being assessed is greater than 1 km^2 or Alternative 2 if the area is less than 1 km^2.

(1) Alternative 1: Based on field reconnaissance, topographic maps, and aerial photographs, estimate the areal extent of the macrotopographic features in the assessment area.

(2) Alternative 2: Based on field reconnaissance, topographic maps, and aerial photographs, estimate the areal extent of the macrotopographic features in a 1-km^2 area around the assessment area. For instance, a 1-km^2 template can be placed on a map or aerial photograph of appropriate scale, and the percentage of that area covered by macrotopographic features can be estimated.

(3) Report the percentage of the area being assessed that is covered with macrotopographic features.

In western Kentucky reference wetlands, macrotopographic features covered between zero and 50 percent of the area being assessed (Appendix D). Based on the range of values from reference standard wetlands, a variable subindex of 1.0 is assigned when the percentage of the

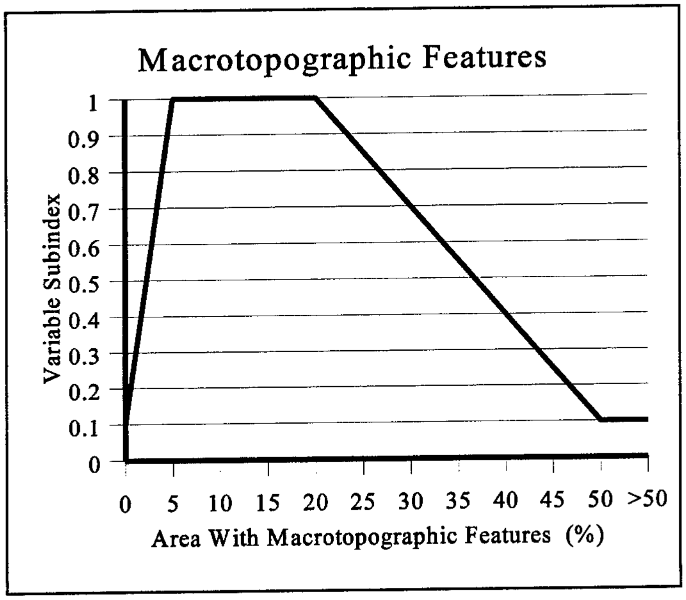


Figure 44. Relationship between macrotopographic features and functional capacity

area being assessed with macrotopographic features is between 5 and 20 percent (Figure 44). As the percent of area with macrotopographic features decreases, the subindex decreases linearly down to a 0.1 when zero percent of the area is covered with macrotopographic features. This is based on the assumption that as the extent of ponding decreases, so does available habitat. As the percent of area with macrotopographic features exceeds 20 percent, a linearly decreasing subindex down to 0.1 is assigned at ≥50 percent macrotopographic features. This is based on the assumption that as macrotopographic features exceed 50 percent, wildlife habitat is affected adversely because much of the terrestrial topographic diversity is replaced with open water.

Plant species composition (V_{COMP}). Plant species composition represents the diversity of plants in riverine wetlands. In general, a healthy, mature forest with a characteristic composition of plant species in each vegetation stratum will support higher species diversity than younger stands due to the greater overall complexity. Plant species composition is important to avifauna because of food sources produced (i.e., hard mast, soft mast, fruits, and seeds), timing of food production (spring seeds vs. autumn production of acorns), and cover and nesting sites provided. Ideally, determining plant species diversity requires an intensive survey of all herbaceous and woody species in all vegetation strata. Unfortunately, the time and taxonomic expertise required to accomplish this is not available in the context of rapid assessment. Thus, the focus here is on the dominant species in each vegetation stratum.

Percent concurrence with the dominant species in all vegetation strata is used to quantify this variable. The procedure for measuring this variable is described on page 76.

In western Kentucky reference wetlands, percent concurrence of dominant species ranged from zero to 100 percent (Appendix D). Based on the data from reference standard sites supporting mature, and fully stocked forests, a variable subindex of 1.0 is assigned when dominant species concurrence is 100 percent (Figure 45). As percent concurrence decreases, a linearly decreasing subindex down to zero is assigned based on the assumption that the relationship between plant species composition and the capacity of the riverine wetland to support a diverse avifaunal community is linear. This assumption can be validated using the independent, quantitative measures of function identified above.

Tree biomass (V_{TBA}). This variable represents the total mass of organic material per unit area in the tree stratum. Trees are defined as woody stems ≥6 m in height and ≥10 cm in diameter at breast height (dbh), which is 1.4 m above the ground (Bonham 1989). Tree biomass is

correlated with forest maturity (Brower and Zar 1984) and, in the context of this function, serves as an indicator of plant community structure.

Tree basal area is used to quantify this variable. The procedure for measuring this variable is described on page 43.

In western Kentucky reference wetlands, tree basal area ranged from 0 to 28 m^2/ha (Appendix D). Based on the data from reference standard sites supporting mature and fully stocked forests, a variable subindex of 1.0 is assigned when tree basal area is ≥18 m^2/ha (Figure 46). At reference sites in the middle to early stages of succession, or cleared for agriculture, tree basal area decreases, and a linearly decreasing subindex down to zero at zero tree basal is assigned. This is based on the assumption that the relationship between tree basal area and the capacity of the riverine wetland to provide habitat is linear. This assumption could be validated using the data from a variety of low gradient, riverine wetlands in the Southeast, summarized by Brinson (1990), Christensen (1991), Sharitz and Mitsch (1993), and Messina and Conner (1997), or the independent, quantitative measures of function identified above.

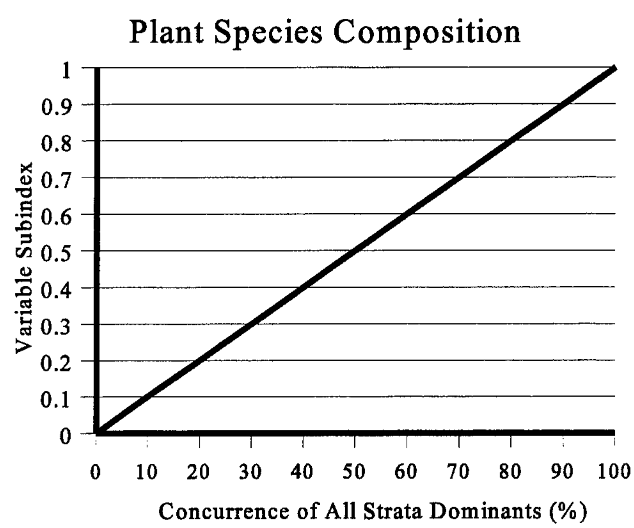


Figure 45. Relationship between percent concurrence of strata dominants and functional capacity

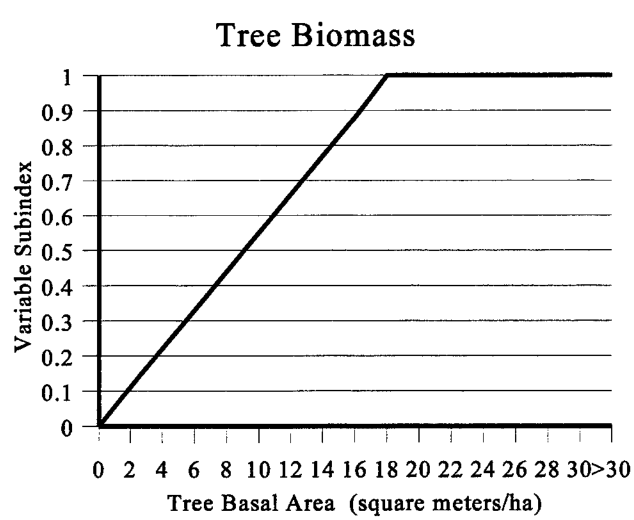


Figure 46. Relationship between tree basal area and functional capacity

Tree Density (V_{TDEN}). This variable represents the number of trees per unit area in riverine wetlands. Trees are defined as woody stems ≥6 m in height and ≥10 cm dbh. In most forested systems, tree stem density and basal area increase rapidly during the early successional phase. Thereafter, tree density decreases and the rate at which basal area increases diminishes as the forest reaches mature steady-state conditions (Spurr and Barnes 1980). In the context of this function, tree density serves as an indicator of plant community structure.

The density of tree stems per hectare is the measure of this variable. Measure it with the following procedure.

(1) Count the number of tree stems in a circular 0.04-ha plot (radius = 11.3 m).

(2) If multiple 0.04-ha plots are sampled, average the results from all plots. The number of 0.04-ha plots required to adequately characterize the area being assessed will depend on its size and heterogeneity. Chapter 5, Assessment Protocols, provides guidance for determining the number and layout of sampling units.

(3) Convert the results to a per hectare basis by multiplying by 25. For example, if the average value from all the sampled plots is 20 stems, then 20 × 25 = 500 stems/ha.

(4) Report tree density in stems/hectare.

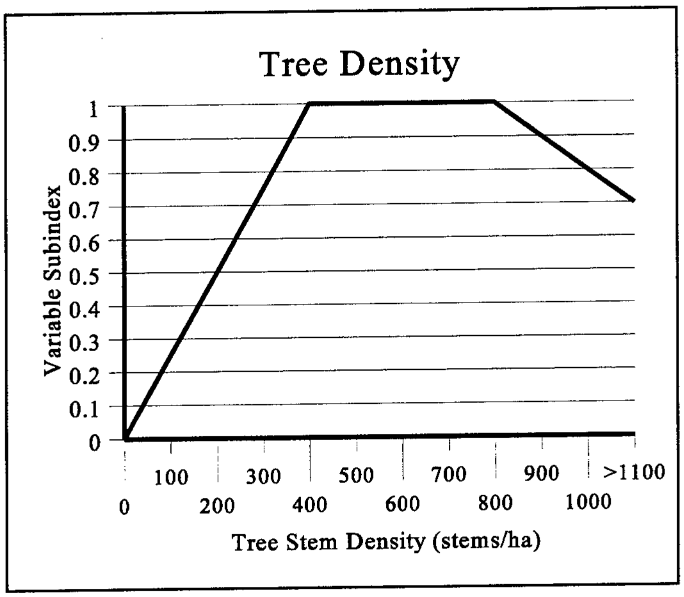


Figure 47. Relationship between tree density and functional capacity

In western Kentucky reference wetlands, tree stem density ranged from zero to 940 stems/ha (Appendix D). Based on the range of values at reference standard wetlands sites, a variable subindex of 1.0 is assigned when tree stem densities are between 400 and 800 stems/ha (Figure 47). At sites that have been cleared for agricultural or other activities, where tree stem density is zero, a subindex of zero is assigned. As tree stem densities gradually increase during the early and midstages of succession, a linearly increasing subindex is assigned up to 1.0 at 400 stems/ha. As secondary succession continues, stem densities often exceed 800 stems/ha, a linearly decreasing subindex down to 0.7 at ≥1,100 stems/ha is assigned. This is based on the assumption that the relationship between tree stem density and the capacity of the riverine wetland to provide wildlife habitat (particularly avifauna) is linear. This assumption could be validated by analyzing the relationship between tree stem density and the capacity to provide wildlife habitat using the data from a variety of low gradient, riverine wetlands in the Southeast, summarized by Brinson (1990), Christensen (1991), Sharitz and Mitsch (1993), and Messina and Conner (1997), or the independent, quantitative measures of function identified above.

Log biomass (V_{LOG}). This variable represents the total mass of organic matter contained in logs on or near the surface of the ground. Logs are defined as down and dead woody stems >7.5 cm (3.0 in.) in diameter that are no longer attached to living plants. In the context of this function, log biomass represents habitat for organisms that utilize logs for refugia, feeding, or breeding.

Volume of woody debris per hectare is used to quantify this variable. The procedure for measuring this variable is described on page 49.

In western Kentucky reference wetlands, the log volume ranged from zero to 75 m^3/ha (Appendix D). Based on data from reference standard sites, a variable subindex of 1.0 is assigned when log volumes are between 10 and 40 m^3/ha (Figure 48). Below 10 m^3/ha the subindex decreases linearly to zero at a log volume of zero m^3/ha. This range of values included reference sites that had been converted to agriculture and had little or no woody debris and sites in early to middle stages of succession with a log volume <10 m^3/ha. The decrease in the variable subindex is based on the assumption that lower volumes of woody debris indicate an inadequate supply of the types of habitat provided by logs. Above 40 m^3/ha the subindex also decreases linearly to 0.45 at 150 m^3/ha. This is based on the assumption that higher log volumes begin to adversely affect the other habitat components in the riverine wetland, but logs are still utilized by wildlife species. This situation occurs after logging or catastrophic wind damage.

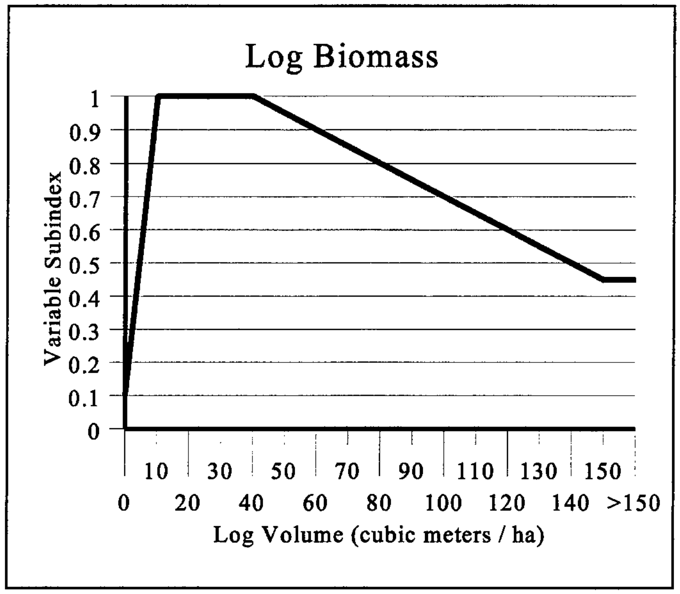


Figure 48. Relationship between log volume and functional capacity

Snag density (V_{SNAG}). This variable represents the number of snags in riverine wetlands. Snags are defined as standing dead woody stems ≥6 m in height and ≥10 cm dbh. In the context of this function, the snag density relates to the suitability of a site as wildlife habitat due to the large number of species that forage on and nest and den in snags.

The density of snag stems per hectare is used to quantify this variable. Measure it with the following procedure.

(1) Count the number of snag stems in a circular 0.04-ha plot.

(2) If multiple 0.04-ha plots are sampled, average the results from all plots. The number of 0.04-ha plots required to adequately characterize the area being assessed will depend on its size and heterogeneity. Chapter 5, Assessment Protocol, provides guidance for determining the number and layout of sample points and sampling units.

(3) Convert the results to a per hectare basis by multiplying by 25. For example, if the average value from all the sampled plots is 2 stems, then 2 × 25 = 50 stems/ha.

(4) Report the density of snags in stems/hectare.

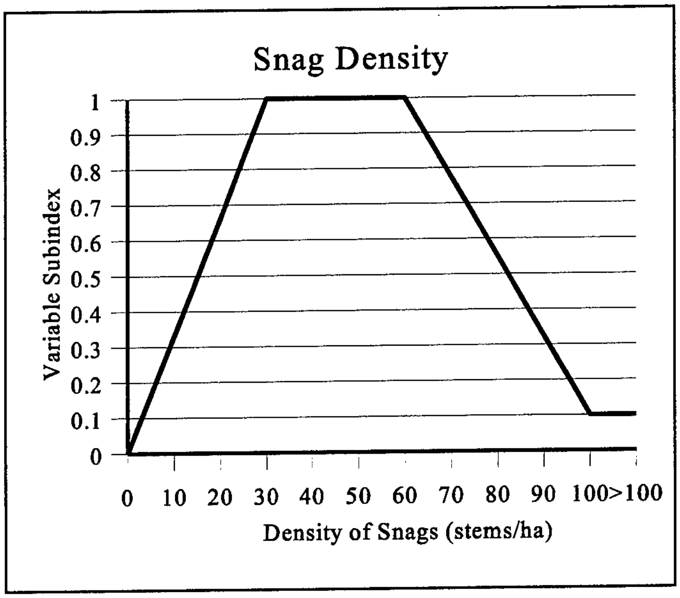


Figure 49. Relationship between snag density and functional capacity

In western Kentucky reference wetlands, snag density typically ranged from zero to 125 stems/ha. However, one site (i.e., IC) had a high density of snags (292 stems/ha) due to recent permanent flooding (Appendix D). Based on the range of values at reference standard wetlands, a variable subindex of 1.0 is assigned when snag densities are between 30 and 60 stems/ha (Figure 49).

Below 30 snags/ha the subindex decreases linearly to zero at a snag density of zero stems/ha. Above 60 snags/ha the subindex decreases linearly to 0.1 at a snag density of ≥100 stems/ha. This is based on the assumption that fewer snags reflect a decrease in the availability of snag habitat and a higher number of snags begin to adversely affect the other habitat components in the riverine wetland.

"O" horizon biomass (V_{OHOR}). This variable represents the total mass of organic matter in the "O" horizon. The "O" horizon is defined as the soil layer dominated by organic material that consists of recognizable or partially decomposed organic matter such as leaves, needles, sticks or twigs < 0.6 cm in diameter, flowers, fruits, insect frass, moss, or lichens on or near the surface of the ground (USDA SCS 1993). The "O" horizon is synonymous with the term detritus or litter layer used by other disciplines. In the context of this function, this variable represents the importance of leaves and small woody debris for the production of many wetland forest invertebrates upon which many avifaunal species feed.

Percent cover of the "O" soil horizon is used to quantify this variable. The procedure for measuring this variable is described on page 47.

In western Kentucky reference wetlands, percent "O" horizon cover ranged from zero to 100 percent (Appendix D). Based on data from reference standard sites, a variable subindex of 1.0 is assigned when the "O" soil horizon cover is >60 percent (Figure 50). This was after deletion of the lowest value (25 percent), which occurred at a site near the confluence of Drakes Creek and Pond River where scouring flows had removed the "O" horizon. As "O" horizon cover decreases, a linearly decreasing subindex down to zero at zero percent cover is assigned. The rate at which the subindex decreases, and the selection of zero as the subindex endpoint at zero percent cover, is based on the assumption that the relationship between "O" soil horizon cover and opportunities for ground feeding species is linear. When "O" soil horizon drops to zero percent, no habitat for litter dwelling invertebrate species is available, thus feeding opportunities for ground feeding birds have essentially ceased. These assumptions could be validated using the independent, quantitative measures of function defined above.

Description of landscape scale model variables

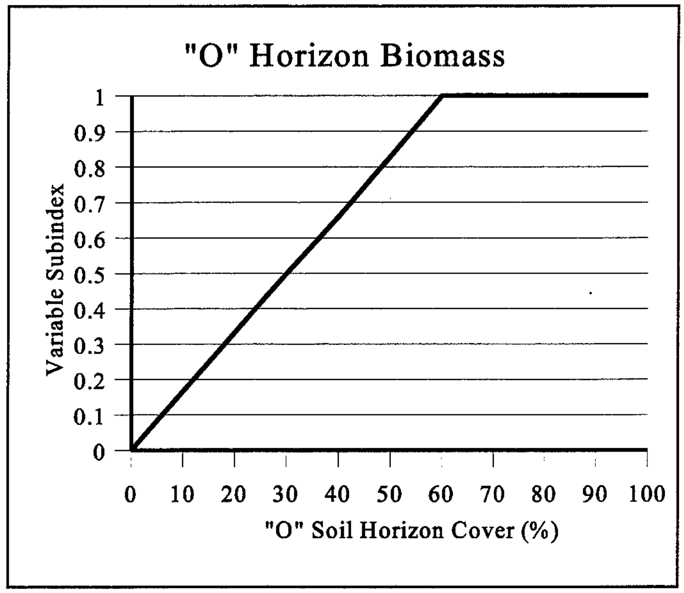


Figure 50. Relationship between "O" soil horizon and functional capacity

This section describes model variables used to assess the capacity of the forested wetland tract to support wildlife species in a landscape context. The size of the tract is perhaps the most important determinant of forest species richness with larger tracts supporting more species (i.e., the species-area concept). However, size alone is not the only factor affecting the suitability of a particular tract to support a bottomland hardwood wildlife community. Habitat fragmentation can modify the effective size of the forested wetland tract, which affects the ability of the tract to contribute to the long-term wildlife richness (Schroeder, O'Neil, and Pullen in preparation; Schroeder 1996a,b). The assumptions incorporated into the following landscape variables are:

a. Large tracts with a high ratio of interior to edge habitat are preferred over smaller ones with little interior habitat

b. Other types of "natural" habitat, including upland areas, are important to wildlife, and, the closer together these areas are, the greater the diversity of wildlife utilizing them

c. The landscape for which these model variables were scaled (western Kentucky) is fragmented by agriculture and surface coal mining. In largely unfragmented landscapes, these variables would have to be rescaled since faunal populations respond differently in these landscapes than in fragmented landscapes.

The following variables assess the ability of the wetland tract to support wildlife populations based not only on its inherent capability but on its position in the landscape.

Wetland tract area (V_{TRACT}). This variable is the area of low gradient, riverine wetland that is contiguous and directly accessible to wildlife from the area being assessed (Figure 51). In the context of this function, this variable represents the fact that wildlife movement is not constrained by imaginary lines on a map such as project boundaries. Although species dependent, wildlife movement is more likely to be constrained by factors such as the size of home range, and ecologically meaningful boundaries are more likely to be distinguished by changes in land use, habitat type, or structures such as roads.

The area of wetland that is contiguous with the area being assessed and of the same regional wetland subclass is used to quantify this variable. Measure it with the following procedure.

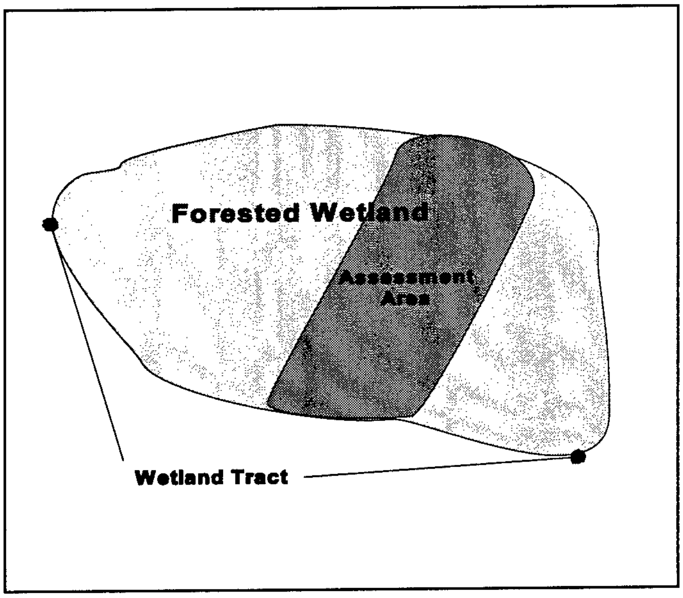


Figure 51. Relationship of assessment area to the larger area of contiguous wetland of the same subclass for determining wetland tract

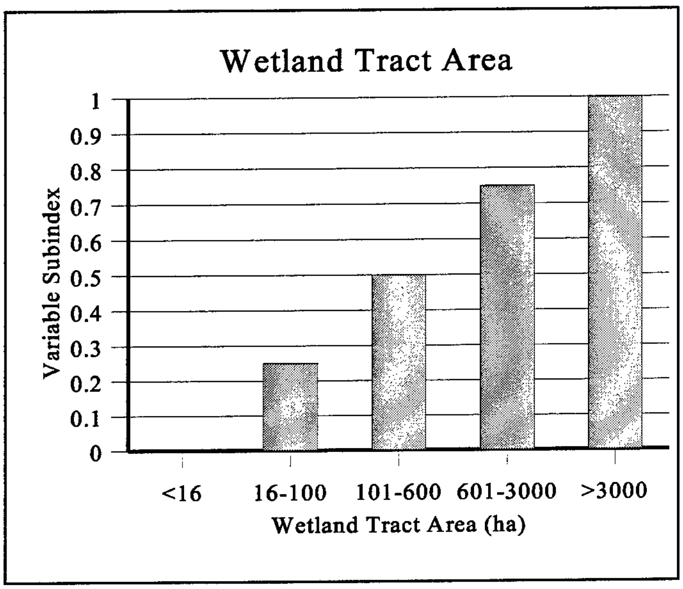


Figure 52. Wetland tract size and functional capacity

(1) Determine the size of the area of wetland of the same regional subclass that is contiguous with the assessment area using field reconnaissance, topographic maps, National Wetland Inventory maps (NWI), or aerial photography.

(2) Record the size of the area in hectares.

In western Kentucky reference wetlands, wetland tract size ranged from 6 to 4,800 ha (Appendix D). This range assumes that two-lane State highways and powerline corridors do not represent significant barriers to most wildlife. Larger roads and discontinuities were treated as tract boundaries. Based on data from reference standard sites in west Kentucky and avifauna data from forested wetland tracts in the mid-Atlantic region (Schroeder 1996b; Robbins, Dawson, and Dowell 1989), a variable subindex of 1.0 is assigned when wetland tract size is >3,000 ha since this is the minimum needed to retain all breeding forest birds (Figure 52). Wetland tracts between 601-3,000 ha (1,500-7,500 acres) are assigned a subindex of 0.7 since 12 forest interior bird species occur at 100 percent frequency in tracts as small as 600 ha (1,500 acres) (Blake and Karr 1984). Wetland tracts between 101-600 ha (250-1,500 acres) are assigned a subindex of 0.5 since at 100 ha (250 acres) 87 percent frequency of occurrence of interior bird species has been documented (Temple 1986). Wetland tracts between 16-100 ha (40-250 acres) receive a model variable subindex of 0.3 since tracts greater than 16 ha regularly contain interior bird species (Blake and Karr 1984). Wetland tracts between 1-16 ha (2.5-40 acres) receive a model variable subindex of 0.0 since they contain virtually no interior birds (Blake and Karr 1984).

Interior core area (V_{CORE}). This variable represents the interior portion of a wetland tract with at least a 300-m (990-ft) buffer separating it from adjacent nonforested habitat (Figure 53).

Interior core area is dictated by both the size and shape of the wetland. Large wetland tracts often have large interior core areas, but not always. For example, a large wetland tract that is circular in shape will have a much larger interior core area than a linearly shaped wetland tract of the same size. In the context of this function, this variable represents the availability of forested interior core areas that benefit forest interior bird species which are adversely affected by forest fragmentation and the creation of edge habitat.

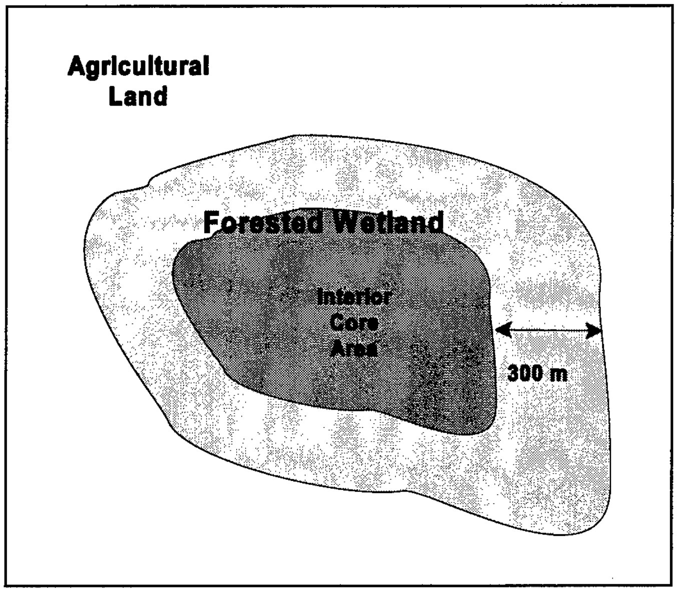


Figure 53. Interior core area and buffer zone

The percentage of the wetland tract inside a buffer zone >300 m separating it from nonforested habitat is used to quantify this variable. Measure it with the following procedure.

(1) Determine the area of the wetland tract within a buffer of at least 300 m using field reconnaissance, topographic maps, NWI maps, aerial photography, or other sources.

(2) Divide the area of the wetland within the buffer by the total size of the wetland tract and multiply by 300. The result is the percentage of the wetland tract within a buffer zone >300 m.

(3) Report the size of the area within a 300-m buffer as a percentage of total tract area.

In western Kentucky reference wetlands, the percentage of the wetland tract within a buffer of at least 300 m ranged from zero to 56 percent (Appendix D). Based on the range of values from reference standard wetlands, a variable subindex of 1.0 is assigned when 20 percent or more of the wetland tract is inside a buffer of at least 300 m (Figure 54). As the percentage of the wetland tract within a 300-m buffer decreases, a linearly decreasing subindex is assigned down to zero at zero percent of the wetland tract. This is based on the assumption that, as the interior core area decreases, the suitability of the wetland tract for species requiring isolation from predators and parasites that frequent edges also decreases.

Habitat connections ($V_{CONNECT}$). This variable is defined as the percentage of the perimeter of a wetland that is connected to other types of wetlands, upland forests, or other suitable wildlife habitats (Figure 55). Suitable habitats are other forested, naturally vegetated, or wetland areas. Agricultural fields, recent clear cuts, recent mined areas, or developed areas are not considered suitable habitat. An adjacent habitat is considered connected if it is within 0.5 km of the perimeter of the wetland. In the context of this function, this variable represents the need many species of wildlife have for other types of habitat to carry out their daily activities, such as feeding or resting, or to complete a particular phase of their life cycle. Birds and most of the large terrestrial vertebrates are capable of moving substantial distances (i.e., several kilometers)

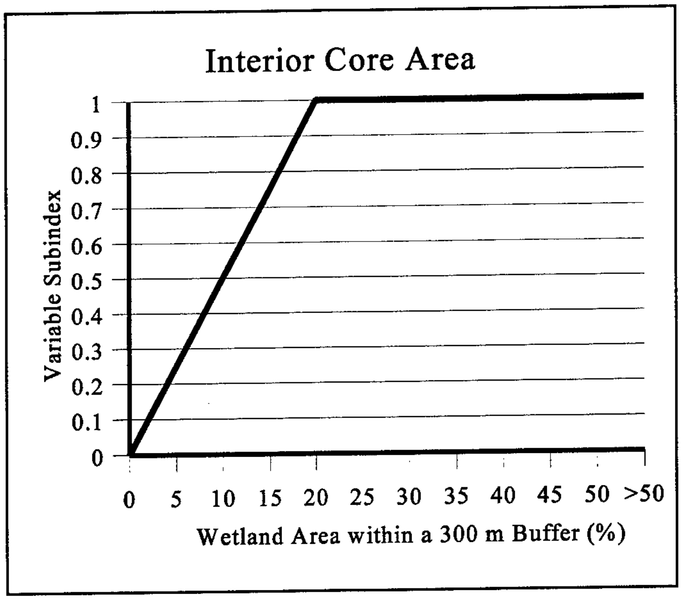


Figure 54. Interior core area and functional capacity

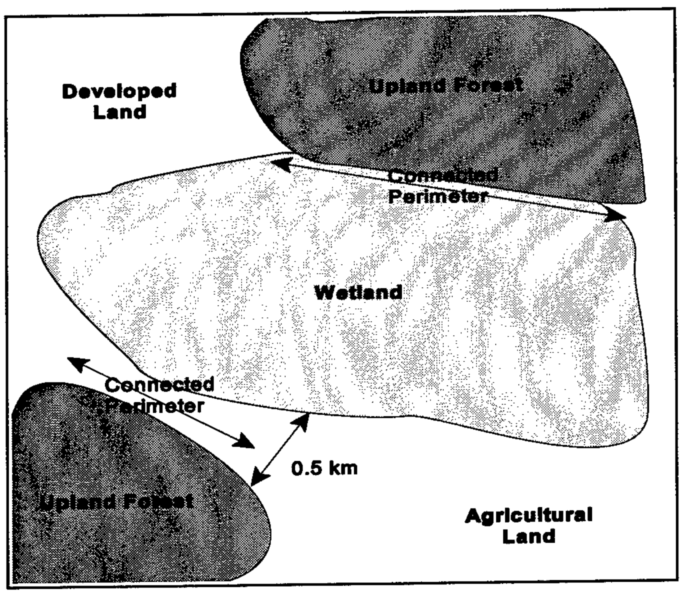


Figure 55. Adjacent habitats which are considered connected and not connected for determining $V_{CONNECT}$

to disjunct patches. Smaller organisms with poor dispersal ability are the focus of this variable. Migration distances for most anurans (frogs, toads, etc.) seldom exceed 1,500 m and most species of salamanders move <500 m (Sinsch 1990). The most restrictive distance, 0.5 km, was chosen as the threshold between connected and disconnected habitats.

The percentage of the perimeter of the wetland tract that is "connected" is used to quantify this variable. Measure it using the following procedure.

(1) Determine the total length of the wetland tract perimeter using field reconnaissance, topographic maps, or aerial photography.

(2) Determine the length of the wetland perimeter that is "connected" to suitable habitats such as other types of wetlands, upland forests, or other wildlife habitats.

(3) Divide the length of "connected" wetland perimeter by the total length of the wetland perimeter.

(4) Convert to a percentage of the perimeter by multiplying by 100.

(5) Report the percentage of the perimeter of the wetland tract that is connected.

In western Kentucky reference wetlands, the ratio of connection to total perimeter length ranged from zero to 85 percent (Appendix D). Based on data from reference standard sites, a variable subindex of 1.0 is assigned when more than 20 percent of the wetland tract perimeter is connected (Figure 56). As the percentage of wetland tract perimeter decreases, a linearly decreasing subindex is assigned down to zero at zero percent connected wetland tract perimeter. This is based on the assumption that, as connections to other suitable habitats decrease, so does

the suitability of the wetland tract as habitat for wide ranging species or for those that move to upland habitat during periods of prolonged inundation.

Functional capacity index

The aggregation equation for deriving the functional capacity index for the wildlife habitat function is as follows:

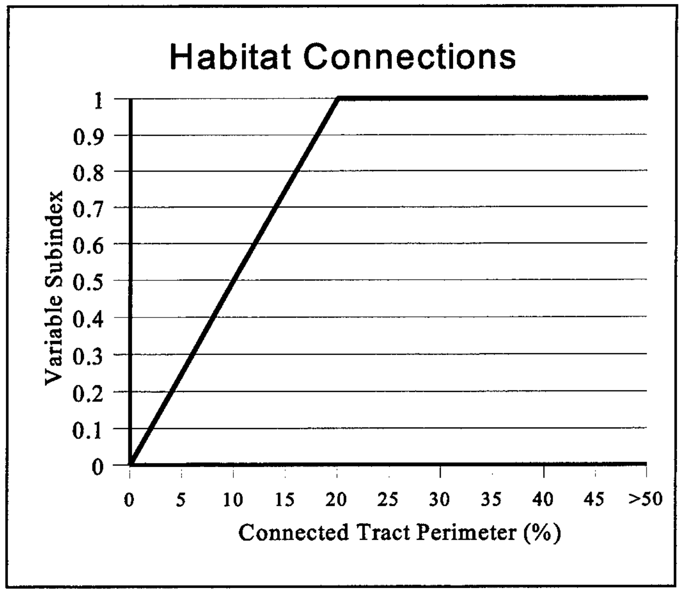


Figure 56. Perimeter tract connections and functional capacity

$$FCI = \left[\frac{\left(\frac{F_{FREQ} + V_{MACRO}}{2} \right) + \left(\frac{V_{TRACT} + V_{CONNECT} + V_{CORE}}{3} \right)}{2} \times \frac{V_{COMP} + V_{TBA} + V_{TDEN} + V_{SNAG} + \left(\frac{V_{LOG} + V_{OHOR}}{2} \right)}{5} \right]^{1/2} \qquad (16)$$

This model is assumed to reflect composition and abundance of avian and other wildlife species in the riverine low gradient subclass. If all these components are similar to reference standard condition (i.e., a large, diverse, unfragmented, mature forested system which floods regularly), there is a high probability that the full complement of birds (and by inference other groups such as small and large mammals, reptiles, amphibians, fish, and invertebrates) typically associated with forested wetlands will be present. The variables have been grouped by the three major components of hydrology, biotic community, and landscape. It should be noted that the emphasis is on onsite conditions. Even in largely fragmented landscapes, if reference standard conditions exist onsite, the majority of fish and wildlife species will be present; however, the site probably would not support some (10-15) area sensitive species of interior birds and large carnivores.

Frequency of overbank flow (V_{FREQ}) is used in this function because a site must flood regularly for species that require water or moist conditions (amphibians and litter invertebrates) to use the wetland. V_{FREQ} also is used to assess whether or not fish and other aquatic organisms can obtain regular access to the floodplain. The assumption is that annual flooding provides optimal access by aquatic organisms. V_{MACRO} is an indicator of the surface complexity of the wetland for fish and other aquatic organisms. The presence of these features is indicative of a diverse

ecosystem and increases the probability of the site supporting a diversity of fish and wildlife. V_{MACRO} also represents the presence of permanent or semipermanent water in the wetland. V_{MACRO} is con-sidered independent of V_{FREQ} since ponding of surface water can occur from water sources besides over-bank flow and ponding is not always a consequence of flooding. Therefore, ponded areas may occur within the wetland in the absence of flooding, and, conversely, flooding may occur with no resulting ponding. Thus, V_{MACRO} and V_{FREQ} are averaged.

The habitat structure has both living and detrital components. The living portion is represented by the variables V_{COMP}, a reflection of the similarity of the community to reference standard conditions, and V_{TDEN} and V_{TBA} , measures of stand maturity, which provide an indication of seral stage. It is assumed that a mature stand composed of species reflective of late seral stages (generally oak-dominated) represents a diverse, stable community with diverse, stable wildlife populations. V_{TDEN} and V_{TBA} also provide an indicator of forest stand structure. The assumption is that, as the stand matures, structure will become more diverse and provide more wildlife habitat. Log volume (V_{LOG}) represents the amount of cover, foraging, and reproductive sites available for a variety of wildlife species. Leaf litter (V_{OHOR}) represents habitat for invertebrates and selected small mammals. Snags (V_{SNAG}) are an important structural component of habitat that serve as perches for birds, provide cavities and dens for numerous species, and provide foraging sites for species that utilize invertebrates. V_{LOG} , V_{OHOR} , and V_{SNAG} are considered independent of one another and are averaged to account for minor structural components of habitat.

The variables wetland tract area (V_{TRACT}), interior core area (V_{CORE}), and connectedness to other habitats ($V_{CONNECT}$) reflect large scale attributes of the wetland and of the landscape in which the wetland is located. The assumption is that, the more habitat there is available, the more wildlife utilization will occur. Essentially, these variables represent two components: size/shape and isolation of the wetland. V_{SIZE} and V_{CORE} represent the size and shape of the wetland and are considered together. $V_{CONNECT}$ represents the isolation of the wetland from adjacent suitable habitats.

In the first subpart of the aggregation equation, the variables representing hydrology are considered equally and are averaged. V_{FREQ} represents delivery of the water to the wetland surface and V_{MACRO} represents detention of the water. In the second subpart of the equation, the landscape level features (V_{TRACT}, $V_{CONNECT}$, *and* V_{CORE}) are considered independently and of equal weight and, consequently, are averaged. Landscape is considered to exert an equivalent influence on the function; therefore, it is averaged with hydrology. In the third subpart of the equation, V_{COMP} , V_{TBA} , V_{TDEN} , V_{LOG} , V_{OHOR} , and V_{SNAG} represent the plant community structure (both living and dead). The first three variables are considered of equal weight and, consequently, averaged. The latter three variables represent significant, but somewhat less important, structural conditions and are averaged separately. The onsite community represents the composition and structural components of habitat and are considered to exert a controlling influence on the function. Thus, the hydrology and landscape components are multiplied by the onsite community and averaged by a geometric mean. This arrangement of the aggregation equation reflects the assumption that site-specific aspects of habitat (i.e., biotic community/habitat structure) carry greater weight than landscape features. In other words, if the onsite community is degraded, the use of that wetland area by wildlife species will decrease even in a relatively unfragmented landscape with intact hydrology.

5 Assessment Protocol

Introduction

Previous sections of this Regional Guidebook provide background information on the HGM Approach and document the variables, measures, and models used to assess the functions of low gradient, riverine wetlands in western Kentucky. This chapter outlines a protocol for collecting and analyzing the data necessary to assess the functional capacity of a wetland in the context of a 404 permit review process or similar assessment scenario.

The typical assessment scenario is a comparison of preproject and postproject conditions in the wetland. In practical terms, this translates into an assessment of the functional capacity of the wetland assessment area (WAA) under both preproject and postproject conditions and the subsequent determination of how FCIs have changed as a result of the project . Data for the pre-project assessment are collected under existing conditions at the project site, while data for the post-project assessment are normally based on the conditions that are expected to exist following proposed project impacts. A skeptical, conservative, and well-documented approach is required in defining postproject conditions. This recommendation is based on the often observed lack of similarity between predicted or "engineered" postproject conditions and actual postproject conditions.

This chapter discusses each of the tasks required to complete an assessment of low gradient, riverine wetlands in western Kentucky, including:

a. Define assessment objectives

b. Characterize the project area

c. Screen for red flags

d. Define the Wetland Assessment Area

e. Collect field data

f. Analyze field data

g. Apply assessment results

Define Assessment Objectives

Begin the assessment process by unambiguously identifying the purpose for conducting the assessment. This can be as simple as stating, "The purpose of this assessment is to determine how the proposed project will impact wetland functions." Other potential objectives could be: (a) compare several wetlands as part of an alternatives analysis, (b) identify specific actions that can be taken to minimize project impacts, (c) document baseline conditions at the wetland site, (d) determine mitigation requirements, (e) determine mitigation success, or (f) determine the effects of a wetland management technique. Frequently, there will be multiple purposes identified for conducting the assessment. Defining the purpose will facilitate communication and understanding between the people involved in conducting the assessment and will make the purpose clear to other interested parties. In addition, it will help to establish the approach that is taken. The specific approach will vary to some degree, depending on whether the project is a Section 404 permit review, an Advanced Identification (ADID), a Special Area Management Plan (SAMP), or some other scenario.

Characterize the Project Area

Characterizing the project area involves describing the project area in terms of climate, surficial geology, geomorphic setting, surface and groundwater hydrology, vegetation, soils, land use, proposed impacts, and any other characteristics and processes that have the potential to influence how wetlands at the project area perform functions. The characterization should be written and should be accompanied by maps and figures that show project area boundaries, jurisdictional wetlands, WAA, proposed impacts, roads, ditches, buildings, streams, soil types, plant communities, threatened or endangered species habitat, and other important features.

The following list identifies some information sources that will be useful in characterizing a project area.

a. Aerial photographs

b. Topographic and National Wetland Inventory maps

c. County Soil Survey

Screen for Red Flags

Red flags are features within, or in the vicinity of, the project area to which special recognition or protection has been assigned on the basis of objective criteria (Table 14). Many red flag features, such as those based on national criteria or programs, are similar from region to region. Other red flag features are based on regional or local criteria. Screening for red flag features represents a proactive attempt to determine if the wetlands or other natural resources in and around the project area require special consideration or attention that may preempt or postpone an assessment of wetland function. The assessment of wetland functions may not be necessary if

Table 14
Red Flag Features and Respective Program/Agency Authority

Red Flag Features	Authority[1]
Native Lands and areas protected under American Indian Religious Freedom Act	A
Hazardous waste sites identified under CERCLA or RCRA	H
Areas protected by a Coastal Zone Management Plan	D
Areas providing Critical Habitat for Species of Special Concern	I
Areas covered under the Farmland Protection Act	K
Floodplains, floodways, or floodprone areas	J
Areas with structures/artifacts of historic or archeological significance	F
Areas protected under the Land and Water Conservation Fund Act	K
Areas protected by the Marine Protection Research and Sanctuaries Act	D
National wildlife refuges and special management areas	I
Areas identified in the North American Waterfowl Management Plan	I
Areas identified as significant under the RAMSAR Treaty	
Areas supporting rare or unique plant communities	
Areas designated as Sole Source Groundwater Aquifers	I
Areas protected by the Safe Drinking Water Act	
City, County, State, and National Parks	F, C, L
Areas supporting threatened or endangered species	B, C, E, G, I
Areas with unique geological features	
Areas protected by the Wild and Scenic Rivers Act	
Areas protected by the Wilderness Act	

[1] Program Authority / Agency
A = Bureau of Indian Affairs
B = National Marine Fisheries Service (NMFS)
C = U.S. Fish and Wildlife Service
D = National Park Service (NPS)
E = State Coastal Zone Office
F = State Departments of Natural Resources, Fish and Game, etc.
G = State Historic Preservation Officer (SHPO)
H = State Natural Heritage Offices
I = U.S. Environmental Protection Agency
J = Federal Emergency Management Administration
K = National Resource Conservation Service
L = Local Government Agencies

the project is unlikely to occur as a result of a red flag feature. For example, if a proposed project has the potential to impact a threatened or endangered species or habitat, an assessment of wetland functions may be unnecessary since the project may be denied or modified strictly on the impacts to threatened or endangered species or habitat.

Define the Wetland Assessment Area

The WAA is an area of wetland within a project area that belongs to a single regional wetland subclass and is relatively homogeneous with respect to the site-specific criteria used to assess wetland functions (i.e., hydrologic regime, vegetation structure, topography, soils, successional stage, etc.). In many project areas, there will be just one WAA representing a single regional wetland subclass as illustrated in Figure 57. However, as the size and heterogeneity of the project area increases, it is more likely that it will be necessary to define and assess multiple WAAs within a project area.

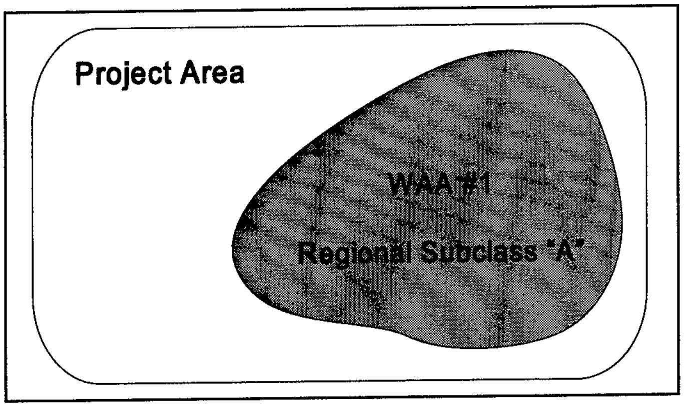


Figure 57. A single WAA within a project area

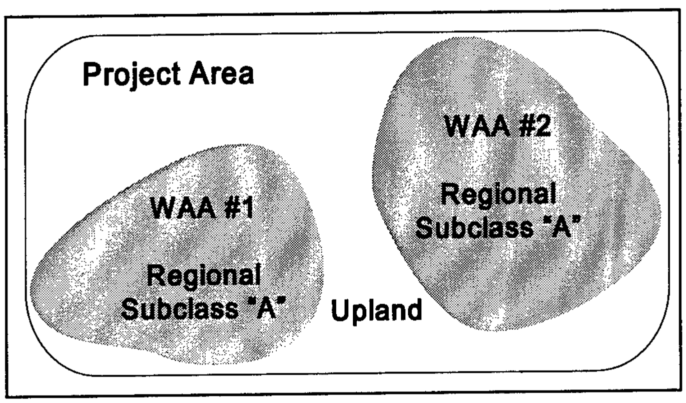


Figure 58. Spatially separated WAA from the same regional wetland subclass within a project area

At least three situations necessitate defining and assessing multiple WAAs within a project area. The first situation exists when widely separated wetland patches of the same regional subclass occur in the project area (Figure 58). The second situation exists when more than one regional wetland subclass occurs within a project area (Figure 59). The third situation exists when a physically contiguous wetland area of the same regional subclass exhibits spatial heterogeneity with respect to hydrology, vegetation, soils, disturbance history, or other factors that translate into a significantly different value for one or more of the site-specific variable measures. These differences may be a result of natural variability (e.g., zonation on large river floodplains) or cultural alteration (e.g., logging, surface mining, hydrologic alterations) (Figure 60). Designate each of these areas as a separate WAA and conduct a separate assessment on each area.

There are elements of subjectivity and practicality in determining what constitutes a "significant" difference in portions of the WAA. Field experience with the regional wetland subclass under consideration should provide the sense of the range of variability that typically occurs and the "common sense" necessary to make reasonable decisions about defining multiple WAAs. For example, in western Kentucky, recently abandoned cropland and land harvested for timber will be two common criteria for designating two WAAs in a wetland area. Splitting an area into many WAAs in a project area, based on relatively minor differences, will lead to a rapid increase in sampling and analysis requirements. In general, differences resulting from natural variability should not be used as a basis for dividing a contiguous wetland area into

multiple WAAs. However, zonation caused by different hydrologic regimes or disturbances caused by rare and destructive natural events (e.g., hurricanes) should be used as a basis for defining WAAs.

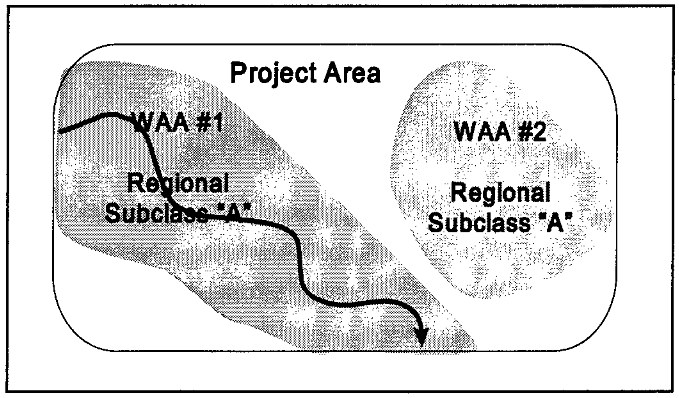


Figure 59. Spatially separated WAA from the same regional wetland subclass within a project area

Collect Field Data

The following equipment is necessary to collect field data.

a. Plant identification keys

b. Soil probe/sharpshooter shovel

c. Munsell color book and hydric soil indicator list (USDA NRCS 1998)

d. Diameter tape or calipers for measuring tree basal area

e. 50-m-distance measuring tape, stakes, and flagging

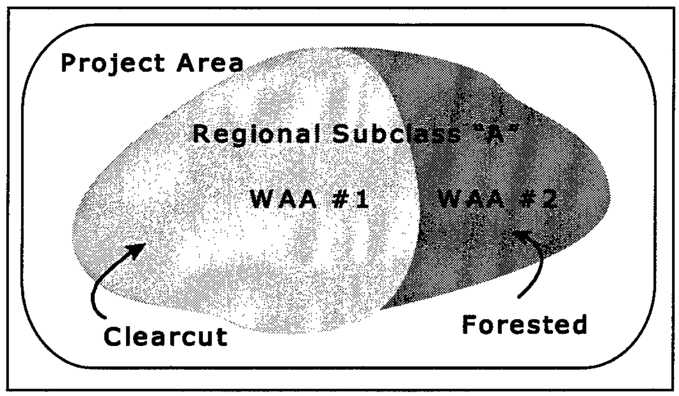


Figure 60. WAA defined based on differences in site specific characteristics.

Information about the variables used to assess the functions of low gradient, riverine wetlands in western Kentucky is collected at several different spatial scales. The Field Data Sheet shown in Figure 61 is organized to facilitate data collection at each spatial scale. Information about landscape scale variables (i.e., variables 1-6 on the Field Data Sheet), such as land use, is collected using aerial photographs, maps, and field reconnaissance of the area surrounding the WAA. Subsequently, information about the WAA in general (i.e., variables 7-17) is collected during a walking reconnaissance of the WAA. Finally, detailed site-specific information (i.e., variables 18-27) is collected using sample plots and transects at a number of representative locations throughout the WAA.

The layout for these plots and transects is shown in Figure 62. The exact number and location of these sample plots and transects are dictated by the size and heterogeneity of the WAA (Davis 1998a). If the WAA is relatively small (i.e., less than 2-3 acres) and homogeneous with respect to the characteristics and processes that influence wetland function, then three or four sample points in representative locations are probably adequate to characterize the WAA. However, as the size and heterogeneity of the WAA increases, more sample plots are required to accurately represent the site.

Field Data Sheet: Low Gradient Riverine Wetlands in Western Kentucky

Assessment Team : ______________________________

Project Name/Location: ______________________________ Date :____________

Sample variables 1-6 using aerial photos, topographic maps, scenic overlooks, local informants, etc.

1. V_{TRACT}	Area of wetland that is contiguous with the WAA *and* of the same subclass	_____	ha
2. V_{CORE}	Percent of wetland tract that is >300 m from unsuitable habitat	_____	%
3. $V_{CONNECT}$	Percent of wetland tract perimeter that is "connected" to suitable habitat	_____	%
4. V_{SLOPE}	Percent floodplain slope	_____	%
5. V_{STORE}	Floodplain width to channel width ratio	_____	
6. V_{MACRO}	Percent of WAA covered with macrotopographic features	_____	%

Sample variables 7-17 based on a walking reconnaissance of the WAA

7. V_{FREQ}	Overbank flood recurrence interval	_____	years
	Check data source: gage data __, local knowledge __, flood frequency curves __, regional dimensionless curve __, hydrologic modeling __, other ______________________.		
8. V_{ROUGH}	Roughness Coefficient ___ (n_{BASE}) + ___ (n_{TOPO}) + ___ (n_{OBS}) + ___ (n_{VEG}) = ...	_____	
9. $V_{SOILINT}$	Percent of WAA with altered soils	_____	%.
10. V_{WTF}	Water table fluctuation is (check one): .... present _____ absent _____		
	Check data source: groundwater well, __ redoximorphic features, __ County Soil Survey __.		
11. V_{WTD}	Water table depth is	_____	inches
	Check data source: groundwater well, __ redoximorphic features, __ County Soil Survey __.		
12. $V_{WTSLOPE}$	Percent of WAA with an altered water table slope	_____	%
13. $V_{SOILPERM}$	Soil permeability	_____	(in/hr)
14. V_{PORE}	Percent effective soil porosity	_____	%
15. $V_{SURFCON}$	Percent of adjacent stream reach with altered surface connections	_____	%
16. V_{CLAY}	Percent of WAA with altered clay content in soil profile	_____	%
17. V_{REDOX}	Redoximorphic features are (check one): .... present _____ absent _____		

Sample variables 18-20 in from a representative number of locations in the WAA using a 0.04-ha circular plot (11.3-m (37-ft) radius)

18. V_{TBA}	Tree basal area (average of 0.04-ha plot values on next line)	_____	m^2/ha
	0.04-ha plots: 1 ____ m^2/ha 2 ____ m^2/ha 3 ____ m^2/ha 4 ____ m^2/ha		
19. V_{TDEN}	Number of tree stems (average of 0.04-ha plot values on next line)	_____	stems / ha
	0.04-ha plots: 1 ____ stems/ha 2 ____ stems/ha 3 ____ stems/ha 4 ____ stems/ha		
20. V_{SNAG}	Number of snags (average of 0.04-ha plot values on next line)	_____	stems / ha
	0.04-ha plots: 1 ____ stems/ha 2 ____ stems/ha 3 ____ stems/ha 4 ____ stems/ha		

Sample variables 21-22 on two (2) 15-m transects partially within the 0.04-ha plot

21. V_{WD}	Volume of woody debris (average of transect values on next line)	_____	m^3/ha
	Transect: 1 ____ m^3/ha 2 ____ m^3/ha 3 ____ m^3/ha 4 ____ m^3/ha		
22. V_{LOG}	Volume of logs (from Plot Worksheet)	_____	m^3/ha
	Transect: 1 ____ m^3/ha 2 ____ m^3/ha 3 ____ m^3/ha 4 ____ m^3/ha		

Sample variable 23 in two (2) 0.004-ha circular subplots (3.6-m (11.8-ft) radius) placed in representative locations of the 0.04-ha plot

23. V_{SSD}	Number of woody understory stems (average of 0.04-ha-plot values on next line)	_____	stems / ha
	0.04-ha plots: 1 ____ stems/ha 2 ____ stem/ha 3 ____ stems/ha 4 ____ stems/ha		

Figure 61. Sample Field Data Sheet (Continued)

Sample variables 24-26 in four (4) square meter subplots placed in representative locations of each quadrant of the 0.04-ha plot		
24. V_{GVC}	Average cover of ground vegetation	____ %
	Average of 0.04-ha plots sampled: 1 ____ % 2 ____ % 3 ____ % 4 ____ %	
25. V_{OHOR}	Average cover of "O" horizon	____ %
	Average of 0.04-ha plots sampled: 1 ____ % 2 ____ % 3 ____ % 4 ____ %	
26. V_{AHOR}	Average cover of "A" horizon (from plot worksheet)	____ %
	Average of 0.04-ha plots sampled: 1 ____ % 2 ____ % 3 ____ % 4 ____ %	
27. V_{COMP}	Concurrence with all strata dominants (from plot worksheet)	____ %
	Average of 0.04-ha plots sampled: 1 ____ % 2 ____ % 3 ____ % 4 ____ %	

Figure 61. (Concluded)

Variables 18-20 are sampled using a circular 0.04-ha (0.01-acre) plot with a radius of 11.3 m. Variables 21 and 22 are sampled along two 15-m transects placed at least partially in the 0.04-ha plot. Variable 23 is sampled using two 0.004-ha (0.001-acre) plots placed in representative portions of the 0.04-ha plot. Vari-ables 24-27 are sampled using four square meter plots placed in represen-tative portions of each quadrant of the 0.04-ha plot.

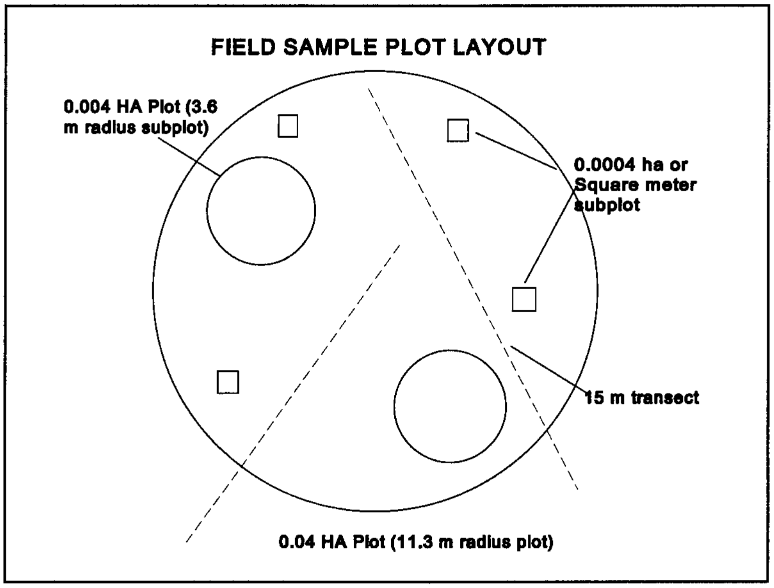


Figure 62. Sample plot and subplot dimensions and layouts for field sampling

For each location in the WAA where plot and transect data are collected (variables 18-16), a Plot Worksheet is filled out (Figure 63). Information from each Plot Worksheet is subsequently transferred to the Field Data Sheet prior to determining the final value for each variable. For example, in calculating variable V_{TBA} (#18) at each sampling location, begin by measuring the diameter at breast height of all trees in the 0.04-ha plot. Record these values by species in the table at the top of the Plot Worksheet, then convert these values to $m^2/0.04$ ha and sum. Carry the summed values down to the first line below the table and convert to m^2/ha. Transfer this value to the Field Data Sheet where all the m^2/ha values from the Plot Worksheet are summarized in the second line of the variable V_{TBA} (#18). To determine the final value of variable V_{TBA} (#18), average the m^2/ha values from each plot and transect sampling locations in the WAA. Complete instructions for collecting each variable in the field are provided in Appendix B along with a blank Plot Worksheet and Field Data Sheet.

Plot Worksheet: Low Gradient Riverine Wetlands in Western Kentucky

Assessment Team : ____

Project Name/Location : ______________________ Plot Number : _____ Date : ________

Record dbh (cm) of trees by species below, square dbh values (cm^2), multiply result by 0.000079 (m^2), and sum resulting values in shaded columns (m^2/0.04 ha). Record in 18. V_{TBA}, multiply by 25 (m^2/h).

Species	dbh (cm)	dbh^2 (cm^2)	× 0.00079 (m^2/0.04 ha)	Species	dbh (cm)	dbh^2 (cm^2)	× 0.00079 (m^2/0.04 ha)

18. V_{TBA} Sum of values from shaded columns above = ______ (m^2/0.04 ha) × 25 = ________ m^2/ha

19. V_{TDEN} Total number of tree stems from above = _______ (stems/0.04 ha) × 25 = ______ stems/ha

20. V_{SNAG} Total number of snag stems from above= _____ (stems/0.04 ha) × 25 = ________ stems/ha

21/22. V_{WD} / V_{LOG}

Record number of stems in Size Class 1 (0.6-2.5 cm / 0.25-1 in) along a 6 ft section of Transect 1 and 2

Transect 1 _______ Transect 2 _______ *Total number of stems* = _______

Size Class 1 tons /acre = 0.187 × *total number of stems* = ... _____ tons/acre

Record number of stems in Size Class 2 (2.5 - 7.6 cm / 1-3 in) along 12 ft section of Transect 1 and 2

Transect 1_______ Transect 2 _______ *Total number of stems* = _______

Size Class 2 tons / acre = 0.892 × *total number of stems* = ... _____ tons/acre

Record diameter of stems in Size Class 3 (> 7.6 cm / >3 in) along 50 ft section of Transect 1 and 2

<u>Transect 1</u>	diameter	diameter^2	<u>Transect 2</u>	diameter	diameter^2
Stem 1 =	_____	_____	Stem 1 =	_____	_____
Stem 2 =	_____	_____	Stem 2 =	_____	_____
Stem 3 =	_____	_____	Stem 3 =	_____	_____
Stem 4 =	_____	_____	Stem 4 =	_____	_____
Total diameter^2		_____	Total diameter^2		_____

Total diameter^2 of stems from both transects = _____

Size Class 3 tons / acre = 0.0687 × *Total diameter ^{2} of stems from both transects* = _____ tons/acre

Total tons / acre (sum of Size Classes 1-3 from above) = ... _____ tons/acre

Cubic feet / acre = (32.05 × *total tons / acre*) / 0.58 = ... _____cubic feet/acre

Cubic meters / ha = *cubic feet / acre* × 0.069 . . . . _____ cubic meters/ha

Figure 63. Sample Plot Worksheet (Continued)

23. V_{SSD}	Tally woody understory stems for two 0.004-ha subplots, then average and multiply by 250: Subplot 1 ________ Subplot 2 ________ Average ____ × 250 = ____ stems/ha	
24. V_{GVC}	Estimate percent cover of ground vegetation in four m^2 subplots, then average: 1 ____ % 2 ____ % 3 ____ % 4 ____ % .... Average _____ %	
25. V_{OHOR}	Estimate percent cover of "O" Horizon in four m^2 subplots, then average: 1 ____ % 2 ____ % 3 ____ % 4 ____ % .... Average _____ %	
26. V_{AHOR}	Estimate percent cover of "A" Horizon in four m^2 subplots, then average: 1 ____ % 2 ____ % 3 ____ % 4 ____ % .... Average _____ %	
27. V_{COMP}	Determine percent concurrence with each strata using the table below Tree = ___ % Shrub/Sapling = ___ % Ground Vegetation = ___ % Average _____ %	

Dominant Species by Strata in Western Kentucky Low Gradient Riverine Wetlands		
Tree	Shrub/Sapling	Ground Vegetation
Acer rubrum	*Acer rubrum*	*Arundinaria gigantea*
Betula nigra	*Betula nigra*	*Aster* sp.
Carya laciniosa	*Carya laciniosa*	*Boehmaria cylindrica*
Celtis laevigata	*Carpinus caroliniana*	*Campsis radicans*
Fraxinus pennsylvanica	*Celtis laevigata*	*Carex squarosa*
Liquidambar styraciflua	*Celtis occidentalis*	*Eragrostis alba*
Quercus pagodifolia	*Fraxinus pennsylvanica*	*Glyceria striata*
Quercus phellos	*Ilex decidua*	*Hypericum* sp.
Quercus lyrata	*Liquidambar styraciflua*	*Impatiens capensis*
Quercus imbricaria	*Nyssa sylvatica*	*Panicum* sp.
Quercus michauxii	*Quercus imbricaria*	*Parthenocissus quinquefolia*
Quercus stellata	*Quercus lyrata*	*Pilea pumila*
Quercus palustris	*Quercus phellos*	*Quercus phellos*
Salix nigra	*Quercus palustris*	*Salix nigra*
	Quercus pagodifolia	*Sauraurus cernuus*
	Quercus stellata	*Smilacina racemosa*
	Platanus occidentalis	*Smilax rotundifolia*
	Salix nigra	*Sparganium* sp.
	Ulmus americana	*Toxicodendron radicans*

Figure 63. (Concluded)

As in defining the WAA, there are clearly an element of subjectivity and practical limitations in determining the number of sample locations for collecting plot and transect-based site-specific data. Experience has shown that the time required to complete an assessment at a several-acre WAA where 3-4 plots are sampled is 2-4 hr. Training and experience will reduce the required time to the lower end of this range.

Analyze Field Data

The analysis of field data requires two steps. The first step is to transform the measure of each assessment variable into a variable subindex. This can be done using the graphs in Appendix B or in a spreadsheet that has been set up to do the calculations automatically. The second step is to insert the variable subindices into the assessment model and calculate the FCI using the relationships defined in the assessment models. Again, this can be done manually or automatically, using a spreadsheet.

Figure 64 shows an example of a spreadsheet that has been set up to do both steps of the analysis. The data from the Field Data Sheet is transferred into the second column of the lower half of the spreadsheet to the right of the variable names. The calculated variable subindex is displayed in the fourth column of the lower half of the spreadsheet. The variable subindices are then used to calculate the FCI using the appropriate assessment model. The resulting FCI is displayed in the first column of the top half of the spreadsheet to the left of each function name. The spreadsheet format allows the user to instantly ascertain how a change in the field measure of a variable will affect the FCI of a particular function by simply entering a new variable measure in the bottom half of the spreadsheet.

Apply Assessment Results

Once the assessment and analysis phases are complete, the results can be used to: (a) compare the same WAA at different points in time, (b) compare different WAAs at the same point in time, (c) compare different alternatives to a project, or (d) compare different hydrogeomorphic classes or subclasses as per Smith et al. (1995) and Davis (1998b).

Variable Subindex and FCI Calculation for Low Gradient Riverine Wetlands in Western Kentucky

FCI	Function
0.94	**Temporarily Store Surface Water**
0.94	**Maintain Characteristic Subsurface Hydrology**
0.81	**Cycle Nutrients**
0.90	**Remove and Sequester Elements and Compounds**
0.96	**Retain Particulates**
0.64	**Export Organic Carbon**
0.91	**Maintain Characteristic Plant Community**
0.88	**Provide Habitat for Wildlife**

>>>>>>> Enter quantitative or categorical measure from Field Data Sheet in shaded cells

Variables	Measure	Units	Subindex
1. Vtract	2000	ha	0.70
2. Vcore	50	%	0.71
3. Vconnect	50	%	1.00
4. Vslope	0.1	%	0.94
5. Vstore	50	%	0.91
6. Vmacro	10	no units	1.00
7. Vfreq	1.5	%	1.00
8. Vrough	2	no units	1.00
9. Vpond	45	%	1.00
10. Vwtf	1	present (1) or absent (0)	1.00
11. Vwtd	0	inches	1.00
12. Vwtslope	0	%	1.00
13. Vsoilperm	1	in/hr	1.00
14. Vpore	30	%	0.75
15. Vsurfcon	80	%	0.20
16. Vclay	40	%	0.60
17. Vredox	1	present (1) or absent (0)	1.00
18. Vtba	25	m2/ha	1.00
19. Vtden	500	stems/ha	1.00
20. Vsnag	25	stems/ha	0.83
21. Vwd	30	m3/ha	1.00
22. Vlog	10	m3/ha	1.00
23. Vssd	200	stems/ha	0.80
24. Vgvc	50	%	0.63
25. Vohor	50	%	0.83
26. Vahor	50	%	0.63
27. Vcomp	80	%	0.80

Figure 64. Example of an FCI calculation spreadsheet

References

Aldridge, B. N., and Garrett, J. M. (1973). "Roughness coefficients for stream channels in Arizona," U.S. Geological Survey Open File Report 49.

Allen, A. W. (1987). "Habitat suitability index models: gray squirrel, revised," U.S. Fish and Wildlife Service. Biological Report 82(10.135).

Ambuel, B., and Temple, S. A. (1983). "Area-dependent changes in the bird communities and vegetation of southern Wisconsin forests," *Ecology* 64, 1057-68.

Anderson, N. H., and Sedell, J. R. (1979). "Detritus processing by macroinvertebrates in stream ecosystems," *Annual Review of Entomology* 24, 351-377.

Arcement, G. J., Jr. and Schneider, V. R. (1989). "Guide for selecting Manning's roughness coefficients for natural channels and flood plains," U.S. Geological Survey Water-Supply Paper 2339, U.S. Government Printing Office, Washington, DC.

Askins, R. A., Philbrick, M. J., and Sugeno, D. S.. (1987). "Relationship between the regional abundance of forest and the composition of forest bird communities," *Biological Conservation* 39, 129-52.

Aust, W. M. (1994). "Timber harvesting considerations for site protection in southeastern forested wet-lands." *Proceedings, Workshop on Water Management in Forested Wetlands*. Technical Publication R8-TP-20, USDA Forest Service, 5-12.

Avery, T. E., and Burkhart, H. E. (1983). *Forest measurements*, 3rd ed. McGraw-Hill. New York.

Bailey, R. G. (1976). "Ecoregions of the United States," U.S. Forest Service, Intermountain Region, Ogden, UT.

Baker, J. A., and Killgore, K. J. (1994). "Use of a flooded bottomland hardwood wetland by fishes in the Cache River System, Arkansas," Technical Report WRP-CP-3, Wetlands Research Program, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Baker, J. A., Killgore, K. J., and Kasul, R. L. (1991). "Aquatic habitats and fish communities in the lower Mississippi River," *Reviews in Aquatic Sciences* 3, 313-56.

Batema, D. L., Henderson, G. S., and Fredrickson, L H. (1985). "Wetland invertebrate distribution in bottomland hardwoods as influenced by forest type and flooding regime." *Proceedings, Fifth Annual Hardwood Conference*, University of Illinois, Urbana, 196-202.

Bicknell, B. R., Imhoff, J. C., Kittle, J. L., Donigan, A. S., and Johanson, R. C. (1993). "Hydrological Simulation Program - Fortran (HSPF): User's manual for release 10.0," EPA 600/3-84-066, U.S. Environmental Protection Agency, Environmental Research Laboratory, Athens, GA.

Bilby, R. E., and Likens, G. E. (1979). "Effect of hydrologic fluctuations on the transport of fine particulate organic carbon in a small stream," *Limnology and Oceanography* 24, 69-74.

Birdsey, R. A. (1992). "Carbon storage and accumulation in U.S. forest ecosystems," General Technical Report WO-59, U.S. Forest Service.

Blake, J. G., and Karr, J. R. (1984). "Species composition of bird communities and the conservation benefit of large versus small forests," *Biological Conservation* 30, 173-87.

Bolen, E. G., Smith, L. M., and Schramm, H. L. (1989). "Playa lakes - prairie wetlands of the southern high plains," *Bioscience* 39, 615-23.

Bonham, C. D. (1989). *Measurements for terrestrial vegetation*. John Wiley and Sons, New York.

Bormann, F. H. (1953). "The statistical efficiency of sample plot size and shape in forest ecology," *Ecology* 34(3), 474-87.

Bormann, F. H., and Likens, G. E. (1970). "The nutrient cycles of an ecosystem," *Scientific American* 223, 92-101.

Bovee, K. D. (1982). "A guide to stream habitat analysis using the in stream flow incremental method-ology," Instream Flow Information Paper No. 12. U.S. Fish and Wildlife Service, OBS-82/26.

Braun, E. L. (1964). *Deciduous forests of eastern North America*. Hafner Publishing Company, New York.

Brinson , M. M. (1977). "Decomposition and nutrient exchange of litter in an alluvial swamp forest," *Ecology* 58, 601-9.

__________. (1985). "Management potential for nutrient removal in forested wetlands." *Ecological considerations in wetlands treatment of municipal wastewaters*. P. J. Godfrey et al., ed., Van Nostrand Reinhold, New York, 405-16.

_________. (1990). "Riverine forests." *Forested wetlands*. A. E. Lugo, M. M. Brinson, and S. Brown, ed., Elsevier Scientific Publishers, Amsterdam, 87-141.

_________. (1993a). "A hydrogeomorphic classification for wetlands," Technical Report WRP-DE-4, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Brinson , M. M. (1993b). "Changes in the functioning of wetlands along environmental gradients," *Wetlands* 13, 65-74.

Brinson , M. M. (1995a). "The hydrogeomorphic approach explained," National Wetlands Newsletter, November/December, Environmental Law Institute, Washington, DC.

_________. (1995b). "Assessing wetland functions using HGM," National Wetlands Newsletter, January/February, Environmental Law Institute, Washington, DC.

Brinson, M. M., Bradshaw, H. D., and Kame, E. S. (1984). "Nutrient assimilative capacity of an alluvial floodplain swamp," *Journal of Applied Ecology* 21, 1041-57.

Brinson, M. M., Bradshaw, H. D., Holmes, R. N., and Elkins, J. B. (1981). "Riparian ecosystems: their ecology and status," FWS/OBS-81/17, Biological Service Program, U.S. Fish and Wildlife Service. Washington, DC.

Brinson, M. M., Hauer, F. R., Lee, L. C., Nutter, W. L., Rheinhardt, R. D., Smith, R. D., and Whigham, D. (1995). "A guidebook for application of hydrogeomorphic assessments to riverine wetlands," Wetlands Research Program Technical Report WRP-DE-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Brinson, M. M., Lugo, A. E., and Brown, S. (1981). "Primary productivity, decomposition and consumer activity in freshwater wetlands," *Annual Review of Ecology and Systematics* 12, 123-61.

Brinson, M. M., Nutter, W. L., Rheinhardt, R., and Pruitt, B. A. (1996). "Background and recommendations for establishing reference wetlands in the Piedmont of the Carolinas and Georgia," EPA/600/R-96/057, U.S. Environmental Protection Agency National Health and Environmental Effects Laboratory, Western Division, Corvallis, OR.

Brinson, M. M., Smith, R. D., Whigham, D. F., Lee, L. C., Rheinhardt, R. D., and Nutter, W. L. (1998). "Progress in development of the hydrogeomorphic approach for assessing the functioning of wetlands." *Proceedings, INTECOL International Wetland Conference*. Perth, Australia.

Brittingham, M. C., and Temple, S. A. (1983). "Have cowbirds caused forest songbirds to decline?" *BioScience* 33, 31-5.

Brooks, K. N., Ffolliott, P. F., Gregerson, H. M., Thames, J. L. (1991). *Hydrology and the management of watersheds*. Iowa State University Press, Ames, IA.

Brower, J. E., and Zar, J. H. (1984). *Field and laboratory methods for general ecology.* William C. Brown Company, Dubuque, IA.

Brown, J. K. (1974). "Handbook for inventorying downed woody material," General Technical Report INT-16, USDA Forest Service.

Brown, J. K., Oberheu, R. D., and Johnston, C. M. (1982). "Handbook for inventorying surface fuels and biomass in the interior west," General Technical Report INT-129, USDA Forest Service Inter-mountain Forest and Range Experiment Station, Ogden UT.

Brown, S., and Peterson, D. L. (1983). "Structural characteristics and biomass production of two Illinois bottomland forests," *American Midland Naturalist* 110, 107-17.

Burke, M. (1996). "Historic evolution of channel morphology and riverine wetland hydrologic functions in the Piedmont of Georgia," M.S. thesis, University of Georgia, Athens.

Campbell, K. L., and Johnson, H. P. (1975). "Hydrologic simulation of watersheds with artificial drainage," *Water Resources Research* 11, 120-26.

Choquette, A. F. (1988). "Regionalization of peak discharges for streams in Kentucky," Water-Resources Investigations Report 87-4209, U.S. Geological Survey.

Christensen, N. L. (1991). "Vegetation of the southeastern coastal plain," *North American Terrestrial Vegetation.* M. G. Barbour and W. D. Billings, ed., Cambridge University Press. Cambridge, MA.

Claborn, B. J., and Dodson, R. D. (1992). "Hands-on HEC-1," Dodson and Associates, Houston TX.

Cody, M. L. (1985). *Habitat selection in birds.* Academic Press, Inc., Orlando, FL.

Conger, D. H. (1971). "Estimating magnitude and frequency of floods in Wisconsin," Water Resources Division Open-file Report, U.S. Geological Survey, Madison, WI.

Conner, W. H., and Day, J. W., Jr. (1976). "Productivity and composition of a baldcypress-water tupelo site and bottomland hardwood site in a Louisiana swamp," *American Journal of Botany* 63, 1354-64.

Conner, W. H., and Day, J. W. (1992). "Water level variability and litterfall productivity of forested fresh-water wetlands in Louisiana," *American Midland Naturalist* 128, 237-45.

Cooper, J. R., Gilliam, J. W., and Jacobs, T. C. (1986). "Riparian areas as a control of nonpoint pollu-tants." *Watershed research perspectives.* D. L. Correll, ed., Smithsonian Institution Press, Washington DC.

Cooper, J. R., Gilliam, J. W., Daniels, R. B., and Robarge, W. P. (1987). "Riparian areas as filters for agricultural sediment," *Soil Science Society of America Journal* 51(2), 416-20.

Cobb, G. H. (1989). "The habitat diversity and fish reproductive function of floodplain ecosystems," *Environmental Biology of Fishes* 26, 1-27.

__________. (1997). "Importance of marinas and off-channel water bodies as refuges for young fishes in a regulated lowland river," *Regulated Rivers: Research and Manangement* 13, 303-07.

Cowardin, L. M., Carter, V., Golet, F. C., and LaRoe, E. T. (1979). "Classification of wetlands and deepwater habitats of the United States," Office of Biological Services Report FWS/OBS-79/31, U.S. Fish and Wildlife Service, Washington, DC.

Cox, G. W. (1980). *Laboratory manual of general ecology.* William C. Brown Company, Dubuque, IA.

Crow, J. H., and MacDonald, K. B. (1978). "Wetland values: Secondary productivity," *Wetland functions and values: the state of our understanding.* P. E. Greeson, J. R. Clark, and J. E. Clark, ed., American Water Resources Association, Minneapolis, MN.

Dahm, C. M. (1981). "Pathways and mechanisms for removal of dissolved organic carbon from leaf leachates in streams," *Canadian Journal of Fish and Aquatic Science* 38, 68-76.

Dawson, K. J., and Istok, J. D. (1991). *Aquifer testing.* Lewis Publishers, Inc., Chelsea, MI.

Day, F. P. (1979). "Litter accumulation in four plant communities in the Dismal Swamp, Virginia," *American Midland Naturalist* 102, 281-89.

Day, J. W., Jr., Butler, T. J., and Conner, W. H. (1977). "Productivity and nutrient export studies in a cypress swamp and lake system in Louisiana." *Estuarine processes, volume II.* M. L. Wiley, ed., Academic Press, New York.

Demissie, M., and Kahn, A. (1993). "Influence of wetlands on streamflow in Illinois," Illinois State Water Survey.

Dewey and Kropper Engineers. (1964). "Effect of loss of valley storage due to encroachment—Connecticut River," Report to the Water Resources Commission, Hartford, CT.

Dickinson, C. H., and Pugh, G. (1974). *Biology of plant litter decomposition, volume I.* Academic Press, London, England.

Dickson, J. G. (1978). "Forest bird communities of the bottomland hardwoods." *Proceedings, workshop on management of southern forests for nongame birds.* USDA Forest Service Southeastern Forest Experiment Station GTR-SE-14, Asheville, NC.

Drees, L. R., Karathanasis, A. D., Wilding, L. P., and Blevins, R. L. (1994). "Micromorphological characteristics of long-term no-till and conventionally tilled soils," *Soil Sci. Soc. Am. J.* 58, 508-17.

Drury, G. H. (1964). "Principles of underfit streams," Professional Paper 452A, U.S. Geological Survey, Washington, DC.

__________. (1977). "Underfit streams: Retrospect, perspect, and prospect." *River channel changes*. K. J. Gregory, ed., John Wiley and Sons, New York, 281-93.

Duellman, W. E., and Trueb, L. (1986). *Biology of amphibians*. McGraw-Hill, New York.

Dunne, T., and Leopold, L. B. (1978). *Water in environmental planning*. W. H. Freeman and Company, San Francisco, CA.

Dybvig, W. L., and Hart, J. R. (1977). "The effects of agricultural drainage on flood flows at Moose Jaw." *Proceedings, 1977 Canadian hydrology symposium*. National Resources Council, 311-21.

Edwards, R. T. (1987). "Sestonic bacteria as a food source for filtering invertebrates in two southeastern blackwater streams," *Limnology and Oceanography* 32, 221-34.

Edwards, R. T., and Meyers, J. L. (1986). "Production and turnover of plantonic bacteria in two sub-tropical blackwater rivers," *Applied Environmental Microbiology* 52, 1317-23.

Elder, J. F. (1982). "River transport of nutrients and detritus to the Apalachicola Bay estuary, Florida," *Water Resources Bulletin* 18, 849-56.

__________. (1985). "Nitrogen and phosphorus speciation and flux in a large Florida river-wetland system," *Water Resources Research* 21, 724-32.

Elder, J. F., and Cairns, D. J. (1982). "Production and decomposition of forest litter fall on the Appalachicola River flood plain, Florida," Water Supply Paper 2196-B, U.S. Geological Survey, Washington, DC.

Elder, J. F., and Mattraw, H. (1982). "Riverine transport of nutrients and detritus to the Apalachicola Bay Estuary, Florida," *Water Resources Bulletin* 18, 849-856.

Elton, C. S. (1968). *The pattern of animal communities*. Methuen, London.

Elwood, J. W., Newbold, J. D., O'Neill, R. V., and Van Winkle, W. (1983). "Resource spiraling: An operational paradigm for analyzing lotic ecosystems," *Dynamics of lotic ecosystems*. T. D. Fontaine and S. M. Bartell, ed., Ann Arbor Science, Ann Arbor, MI.

Environmental Laboratory. (1987). "Corps of Engineers Wetlands Delineation Manual," Technical Report Y-87-1, U. S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Estes, C. C., and Orsborn, J. F. (1986). "Review and analysis of methods for quantifying instream flow requirements," *Water Resources Bulletin* 22, 389-98.

Ewel, K. C., and Odum, H. T. (1984). *Cypress swamps.* University Presses of Florida, Gainesville, FL.

Faulkner, S. P., and Richardson, C. J. (1989). "Physical and chemical characteristics of freshwater wetland soils." *Constructed wetlands for wastewater treatment.* D. A. Hammer, ed., Lewis Publishers, Chelsea, MI.

Fenneman, N. M. (1938). *Physiography of the eastern United States.* McGraw-Hill, New York.

Ferren, W. R., Jr., Fiedler, P. L., and Leidy, R. A. (1996). "Wetlands of California. Part I. History of Wetland Habitat," *Madrono* 43, 105-24.

Ferren, W. R., Jr., Fiedler, P. L., Leidy, R. A., Lafferty, K. D., and Mertes, L. A. K. (1996a). "Wetlands of California. Part II. Classification and description of wetlands of the central California and southern California coast and coastal watershed," *Madrono* 43, 125-82.

__________. (1996b). "Wetlands of California. Part III. Key to the catalogue of wetlands of the central California and southern California coast and coastal watershed," *Madrono* 43, 183-233.

Fetter, C. W. (1988). *Applied hydrology.* 2nd ed., Macmillan College Publishing Company, New York.

Fetter, C. W., Jr. (1980). *Applied hydrogeology.* Charles E. Merrill Publishing Co., Columbus.

Finch, D. M. (1991). "Population ecology, habitat requirements, and conservation of neotropical migratory birds," General Technical Report RM-205, U.S. Department of Agriculture Forest Service.

Fralish, J. S. (1994). "Composition, diversity and environmental relationships of the central hardwood bottomland forest." *Management of forested wetland ecosystems in the central hardwood region: Proceedings of a regional management workshop.* S. C. Roberts and R. A. Rathfon, ed., 39-45.

Fredrickson, L. H. (1978). "Lowland hardwood wetlands: current status and habitat values for wildlife," *Wetland functions and values: The state of our understanding.* P. E. Greeson, J. R. Clark, and J. E. Clark, ed., American Water Resources Association, Minneapolis, MN, 207-306.

Freeze R. A., and Cherry, J. A. (1979). *Groundwater.* Prentice Hall, Englewood Cliffs, NJ.

Fremling, C. R., Rasmussen, J. L., Sparks, R. E., Cobb, S. P., Bryan, C. F., and Claflin, T. O. (1989). "Mississippi River fisheries: A case history." *Proceedings, international large river symposium.* D. P. Dodge, ed. Canadian Special Publication, *Fisheries and Aquatic Science* 106, 309-51.

Glasgow, L. L., and Noble, R. E. (1971). "The importance of bottomland hardwoods to wildlife," *Proceedings, symposium on southeastern hardwoods.* USDA Forest Service, Southeast Region, Atlanta, GA.

Godshalk, G. , Kleiss, B., and Nix, J. "Influence of a bottomland hardwood wetland on water chemistry of the Cache River, Arkansas," Technical Report CP-7 (in preparation), Wetlands Research Program, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Golet, F. C., and Larson, J. S. (1974). "Classification of freshwater wetlands in the glaciated Northeast," Resource Publication 116, U.S. Fish and Wildlife Service.

Gosselink, J. G., Lee, L. C., and Muir, T. A., ed. (1990). *Ecological processes and cumulative impacts illustrated by bottomland hardwood wetland ecosystems.* Lewis Publishers, Chelsea, MI.

Green, E. J. (1992). "Assessing forest growth with point sample data," *Conservation Biology* 6, 296-97.

Griffith, G. E., Omernik, J. M., Wilton, T. F., and Pierson, S. M. (1994). "Ecoregions and subregions of Iowa: A framework for water quality assessment and management," *Journal of the Iowa Academy of Sciences* 101, 5-13.

Grubb, H. F., and Ryder, P. D. (1972). "Effects of coal mining on the water resources of the Tradewater River Basin, Kentucky," Geological Survey Water-Supply Paper 1940, U.S. Government Printing Office, Washington, DC.

Guillory, U. (1979). "Utilization of an inundated floodplain by Mississippi River fishes," *Florida Science* 42, 222-28.

Gunderson, D. R. (1968). "Floodplain use related to stream morphology and fish populations," *Journal of Wildlife Management* 32, 507-14.

Hamel, P. B. (1989). "Breeding bird populations on the Congaree wetlands in Swamp National Monument, South Carolina." *Freshwater wetlands and wildlife.* R. R. Sharitz and J. W. Gibbons, ed., U.S. Department of Energy Symposium Series No. 61, Oak Ridge, TN.

Harker, D. F., Jr., Warren, M.L., Cambum, K. E., and Cicerello, R. R. (1981). "Aquatic biota and water quality survey of the western Kentucky Coalfield," Technical Report KDNREP, Division of Water.

Harmon, M. E., Franklin, J. F., and Swanson, F. J. (1986). "Ecology of coarse woody debris in temper-ate ecosystems," *Advances in Ecological Research* 15, 133-302.

Harrelson, C. C., Rawlins, C. L., and Potyondy, J. P. (1994). "Stream channel reference sites: An illustrated guide to field technique," General Technical Report RM-245, Rocky Mountain Forest and Range Experiment Station, U.S. Forest Service, Fort Collins, CO.

Harris, L. D. (1985). "Conservation corridors: A highway system for wildlife," ENFO Report 85-5, Environmental Information Center of the Florida Conservation Foundation, Inc., Winter Park, FL.

Harris, L. D. (1988). "Landscape linkages: The dispersal corridor approach to wildlife conservation," *Transactions, North American Wildlife and Natural Resources Conference* 53, 595-607.

Harris, L. D., and Gosselink, J. G. (1990). "Cumulative impacts of bottomland hardwood forest conversion on hydrology, water quality, and terrestrial wildlife." *Ecological processes and cumulative impacts illustrated by bottomland hardwood wetland ecosystems*. J. G. Gosselink, L. C. Lee, and T. A. Muir, ed., Lewis Publishers, Chelsea, MI, 259-322.

Hauer, F. R., and Smith, R D. (1998). "The hydrogeomorphic approach to functional assessment of riparian wetlands: evaluating impacts and mitigation on river floodplains in the U.S.A," *Freshwater Biology* 40, 517-30.

Hawkins, C. P., Murphy, M. L., and Anderson, N. H. (1982). "Effects of canopy, substrate composition, and gradient on the structure of macroinvertebrate communities in Cascade Range streams of Oregon," *Ecology* 63, 1840-56.

Hayes, A. J. (1979). "The microbiology of plant litter decomposition," *Scientific Progress* 66, 25-42.

Hays, R. L., Summers, C., and Seitz, W. (1981). "Estimating wildlife habitat variables," FWS/OBS - 81/47, U. S. Fish and Wildlife Service.

Heath, R. C. (1987). "Basic ground-water hydrology," Water Supply Paper 2220, U.S. Geological Survey. U.S. Government Printing Office, Washington, DC.

Hodges, J. D. (1997). "Development and ecology of bottomland hardwood sites," *Forest Ecology and Management* 90, 117-25.

Howard, R. J., and Allen, J. A. (1989). "Streamside habitats in southern forested wetlands: Their role and implications for management." General Technical Report SE-50, *Proceedings of the symposium: The forested wetlands of the southern United States*. D. D. Hook and R. Lea, ed., USDA Forest Service.

Howe, R. W. (1984). "Local dynamics of bird assemblages in small forest habitat islands in Australia and North America," *Ecology* 65, 1585-1601.

Hubbard, D. E. (1988). "Glaciated prairie wetland functions and values: A synthesis of the literature," *Biological Report* 88, 43. U.S. Fish and Wildlife Service, Washington, DC.

Hunter, M. L. (1990). *Wildlife, forests, and forestry: Principles of managing forests for biological diversity*. Prentice Hall, Englewood Cliffs, NJ.

Hurt, G. W., Whited, P. M., and Pringle, R. F., ed. (1996). "Field indicators of hydric soils in the United States," National Resource Conservation Service, U.S. Department of Agriculture, Fort Worth, TX.

Ismail, I., Blevins, R. L., and Frye, W. W. (1994). "Long-term no-tillage effects on soil properties and continuous corn yields," *Journal of the Soil Science Society of America* 58, 193-198.

James, C. S. (1985). "Sediment transfer to overbank sections," *Journal of Hydraulic Research* 23, 435-52.

Jennings, M. E., Thomas, W. O., Jr., and Riggs, H. C. (1994). "Nationwide summary of U.S. Geological Survey regional regression equations for estimating magnitude and fre-quency of floods for ungaged sites, 1993," Water-Resources Investigations Report 94-4002, U.S. Geological Survey.

Johansson, M. E., Nilsson, C., and Nilsson, E. (1996). "Do rivers function as corridors for plant dispersal?" *Journal of Vegetation Science* 7, 593-98.

Johnson, T. R. (1987). "The amphibians and reptiles of Missouri," Missouri Department of Conservation, Jefferson City, MO.

Johnston, C. A. (1991). "Sediment and nutrient retention by freshwater wetlands: Effects on surface water quality," *Critical Reviews in Environmental Control* 21, 491-565.

Johnston, C. A., Detenbeck, N. E., and Niemi, G. J. (1990). "The cumulative effect of wetlands on stream water-quality and quantity: A landscape approach," *Biogeochemistry* 10, 105-41.

Junk, W. J., Bayley, P. B., and Sparks, R. E. (1989). "The flood-pulse concept in river-floodplain," International Large River Symposium, D. P. Dodge, ed., *Canadian Special Publications in Fisheries and Aquatic Sciences* 106, 110-27.

Kadlec, R. H. (1985). "Aging phenomenon in wastewater wetlands," *Ecological considerations in wet-land treatment of municipal wastewaters*. P. J. Godfrey, ed., Van Nostrand Rheinhold Co., New York.

Kantrud, J. A., Krapu, G. L., and Swanson, G. A. (1989). "Prairie basin wetlands of the Dakotas: A community profile," Biological Report 85 (7.28), U.S. Fish and Wildlife Service, Washington, DC.

Karathanasis, A. D., Bailey, H. H., Barnhisell, R. I., and Blevins, R. L. (1988). "Descriptions and laboratory data for some soils in Kentucky, no. 3. Western coalfield region," Special Report 88-2, University of Kentucky College of Agriculture, Agricultural Experiment Station, Lexington, KY.

Keiser, E. D. (1976). "Herptofaunal survey of the Atchafalaya River Basin," Unpublished report, Center for Environmental Studies, Natural History Museum, Lafayette, LA.

Keller, C. M. E., Robbins, C. S., and Hatfield, J. S. (1993). "Avian communities in riparian forests of different widths in Maryland and Delaware," *Wetlands* 13, 137-44.

Kent, M., and Coker, P. (1995). *Vegetation description and analysis, a practical approach.* John Wiley and Sons, New York.

Kikkawa, J., and Anderson, D. J., ed. (1986). *Community ecology: Pattern and processes.* Blackwell, Melbourne.

Kilgo, J. C., Sargent, R. A., Miller, K. V., and Chapman, B. R. (1997). Landscape influences on breeding bird communities in hardwood fragments in South Carolina," *Wildl. Soc. Bull.* 25, 878-85.

Killgore, K. J., and Baker, J. A. (1996). "Patterns of larval fish abundance in a bottomland hardwood wetland," *Wetlands* 16, 288-95.

Kirkby, M. J., ed. (1978). *Hillslope hydrology.* John Wiley, Chichester, MA.

Kitchens, W. M. , Jr., Dean, J. M., Stevenson, L. H., and Cooper, J. M. (1975). "The Santee Swamp as a nutrient sink." *Mineral cycling in southeastern ecosystems.* F. G. Howell, J. B. Gentry, and M. H. Smith, ed., ERDA Symposium Series 749513. Washington, DC.

Kuenzler, E. J., Mulholland, P. J., Yarbro, L. A., and Smock, L. A. (1980). "Distributions and budgets of carbon, phosphorus, iron, and manganese in a floodplain swamp ecosystem," Report No. 157, Water Resources Institute of the University of North Carolina, Raleigh, NC.

Kurz, H., and Wagner, K. A. (1953). "Factors in cypress dome development," *Ecology* 34, 157-64.

Lambou, V. W. (1959). "Fish populations of backwater lakes in Louisiana," *Transactions of the American Fisheries Society* 88, 7-15.

__________. (1990). "Importance of bottomland hardwood forest zones to fish and fisheries: the Atchafalaya basin, a case history." *Ecological processes and cumulative impacts: Illustrated by bottomland hardwood forests.* J. G. Gosselink, L. C. Lee, and T. A. Muir, ed., Lewis Publishers, Chelsea, MI, 125-93.

Leibowitz, S. G., and Hyman, J. B. (1997). "Use of scale invariance in assessing the quality of judgement indicators," In preparation, U.S. Environmental Protection Agency Laboratory, Corvallis, OR.

Leopold, L. B. (1994). *A view of the river.* Harvard University Press, Cambridge MA.

Lindsey, A. A., Barton, J. D., Jr., and Miles, S. R. (1958). "Field efficiencies of forest sampling methods," *Ecology* 39, 428-44.

Loeb, S. C. (1993). "The role of coarse woody debris in the ecology of southeastern mammals." *Biodiversity and coarse woody debris in southern forests*. GTR-SE-94, J. W. McMinn and D. A. Crossley, ed., USDA Forest Service Southern Research Station, 108-18.

Lowrance, R., Todd, R., Fail, J., Hendrickson, O., Leonard, R., and Asmussen, L. (1984). "Riparian forests as nutrient filters in agricultural watersheds," *Bioscience* 34, 374-77.

Ludwig, J. A., and Reynolds, J. F. (1988). *Statistical ecology: A primer on methods and computing*. John Wiley and Sons, New York.

Lynch, J. F., and Whigham, D. F. (1984). "Effects of forest fragmentation on breeding bird communities in Maryland, USA," *Biological Conserv.* 28, 287-324.

MacArthur, R. H., and Wilson, E. O. (1967). *The theory of island biogeography*. Princeton Univ. Press, Princeton, NJ.

MacArthur, R. H., and MacArthur, J. W. (1961). "On bird species diversity," *Ecology* 42, 594-98.

Martens, L. A. (1968). "Flood inudations and effects of urbanization in metropolitan Charlotte, North Carolina," Water Supply Paper 1591(C), U.S. Geological Survey, Washington, DC.

McGrain, P. (1983). "The geologic story of Kentucky," Special Publ. 8, series XI, Kentucky Geological Survey.

McNab, W. H., and Avers, P. E. (1994). "Ecological subregions of the United States: Section descrip-tions," WO-WSA-5, U. S. Forest Service, Washington, DC.

McNab, W. H., and Bailey, R. G. (1994). "Map unit descriptions of subregions (sections) of the United States: A table to supplement the map of ecoregions and subregions of the United States," U.S. Forest Service, Washington, DC.

Melton, M. A. (1958). "Correlation structure of morphometric properties of drainage systems and their controlling agents," *Journal of Geology* 66, 442-60.

Messina, M. G., and Conner, W. H. (1997). *Southern forested wetlands: Ecology and management*. Lewis Publishers, Boca Raton, FL.

Mitch, P. P., and Gosselink, J. G. (1993). *Wetlands*. Van Nostrand Reinhold, New York.

Mitsch, W. J., Bosserman, R. W., Hill, P. L., Jr., and Taylor, J. R. (1982). "Classification and management of wetlands in the western Kentucky coalfield," First Annual Report, U.S. Fish and Wildlife Service, Agreement No. 14-31-001-9015.

Mitsch, W. J., Dorge, C. L., and Wiemhoff, J. R. (1979). "Ecosystem dynamics and a phosphorus budget of an alluvial cypress swamp in southern Illinois," *Ecology* 60, 1116-24.

Mitsch, W. J., Taylor, J. R., Benson, K. B., and Hill, P. L., Jr. (1983a). "Wetlands and coal surface mining in western Kentucky—A regional impact assessment," *Wetlands* 3, 161-79.

__________. (1983b). "Atlas of wetlands in the principal coal surface mining region of western Kentucky," FWS/OBS - 82/72, U.S. Fish and Wildlife Service, Washington, DC.

Molinas, A., Auble, G. T., Segelquist, C. S., and Ischinger , L. S., ed. (1988). "Assessment of the role of bottomland hardwoods in sediment and erosion control," NERC-88/11, U.S. Fish and Wildlife Service, National Ecology Research Center, Fort Collins, CO.

Morrison, M. L., Marcot, B. C., and Mannan, R. W.. (1992). *Wildlife-habitat relationships: Concepts and applications.* University of Wisconsin Press, Madison, WI.

Mueller, A. J., Loesch, C. R., and Twedt, D. J. (1995). "Development of management objectives for breeding birds." *Proceedings, partners in flight international workshop*. Cape May, NJ.

Mulholland, P. J. (1981). "Organic carbon flow in a swamp-stream ecosystem," *Ecological monographs* 51, 307-32.

Mulholland, P. J., and Kuenzler, E. J. (1979). "Organic-carbon export from upland and forested wetland watersheds," *Limnology and Oceanography* 24, 960-66.

Nadelhoffer, K. J., and Raich, J. W. (1992). "Fine root production estimates and belowground carbon allocation in forest ecosystems," *Ecology* 73, 1139-47.

Nanson, G. C., and Croke, J. C. (1992). "A genetic classification of floodplains," *Geomorphology* 4, 459-86.

National Interagency Implementation Team. (1996). "National action plan to implement the hydrogeomorphic approach (NAP)," Federal Register Vol.61, No.160,42593-42603, Washington, DC.

Nicholas, A. P., and Walling, D. E. (1996). "The significance of particle aggregation in the overbank deposition of suspended sediments on river floodplains," *Journal of Hydrology* 186, 275-93.

Nilsson, C., Gardfjell, M., and Grelsson, G. (1991). "Importance of hydrochory in structuring plant-communities along rivers," *Canadian Journal of Botany* 69, 2631-33.

Noss, R. F., and Harris, L. D. (1986). "Nodes, networks, and MUMs: Preserving diversity at all scales," *Environmental Management* 3, 299-309.

Novitski, R. P. (1978). "Hydrogeological characteristics of Wisconsin's wetlands and their influences on floods, stream flow, and sediment." *Wetland functions and values: The state of our understanding*. P. E. Greeson, J. R. C. Clark, and J. E. Clark, ed., American Water Resources Association, Minneapolis, MN, 377-88.

O'Brian, A. L. (1980). "The role of ground water in stream discharge from two small wetland controlled basins in eastern Massachusetts," *Ground Water* 18, 359-365.

Odum, E. P. (1950). "Bird populations of the Highlands (North Carolina) Plateau in relation to plant succession and avian invasion," *Ecology* 31, 587-605.

Ogawa, H., and Male, J. W. (1983). "The flood mitigation potential of inland wetlands," Publication Number 138, Water Resources Center, Amherst, MA.

________. (1986). "Simulating the flood mitigation role of wetlands," *Journal of Water Resources Planning and Management ASCE* 112, 114-28.

Omernik, J. M., and Gallant, A. L. (1988). "Ecoregions of the upper midwest states," Technical Report EPA/600/3-88/037, Environmental Research Laboratory, U.S. Environmental Protection Agency, Corvallis, OR.

Ovington, J. D. (1965). "Organic production, turnover and mineral cycling in woodlands," *Biological Review* 40, 772-85.

Patrick, W. H., Jr., and Tusneem, M. E. (1972). "Nitrogen loss from flooded soil," *Ecology* 53, 735-37.

Patton, P. C. (1988). "Drainage basin morphometry and floods." *Flood geomorphology*. V. R. Baker, R. C. Kochel, and P. C. Patton, ed., John Wiley and Sons. New York, 51-64.

Patton, P. C., and Baker, V. R. (1976). "Morphometry and floods in small drainage basins subject to diverse hydrogeomorphic controls," *Water Resources Research* 12, 941-52.

Perry, D. A. (1994). *Forest ecosystems*. Johns Hopkins University Press, Baltimore, MD.

Peterjohn, W. T., and Correll, D. L. (1984). "Nutrient dynamics in an agricultural watershed—Observations on the role of a riparian forest," *Ecology* 65, 1466-75.

Pielou, E. C. (1984). *The Interpretation of Ecological Data*. John Wiley and Sons. New York.

Pomeroy, L. R. (1970). "The strategy of mineral cycling," *Annual Review of Ecology and Systematics 1*, 171-90.

Price, M. (1977). "Techniques for estimating flood-depth frequency relations on natural streams in Georgia," Water Resources Investigations Report 77-90, U. S. Geological Survey, Doraville, GA.

Pruitt, B. A., and Nutter, W. L. "Channel-full flood frequency relationships in southern Piedmont water-sheds," Unpublished manuscript. Ecological Evaluation Section, U.S. Environmental Protection Agency, Region IV, Athens, GA.

Pugh, G., and Dickinson, C. H. (1974). *Biology of plant litter decomposition. Volume II.* Academic Press, London.

Quinones, F., York, K. L., and Plebuch, R. O. (1983). "Hydrology of area 34, eastern region, interior coal province, Kentucky, Indiana and Illinois," Water Resources Investigations Open File Report 82-638, U.S. Geological Survey, Louisville, KY.

Raich, J. W., and Nadelhoffer, K. J. (1989). "Belowground carbon allocation in forest ecosystems: Global trends," *Ecology* 70, 1346-54.

Rawls, W. L., Ahuja, L. R., Brakensiek, D. L., and Shirmohammadi, A. (1993). "Infiltration and soil water movement," *Handbook of hydrology*. D. R. Maidment, ed., McGraw-Hill, Inc., New York, 5.14.

Reinecke, K. J., Kaminski, R. M., Moorhead, D. J., Hodges, J. D., and Nassar J. R. (1989). "Mississippi alluvial valley." *Habitat management for migrating and wintering waterfowl in North America*. L. M. Smith, R. L. Pederson, and R. M. Kaminski, ed., Texas Tech University Press, Lubbock, TX, 203-47.

Reiners, W. A. (1972). "Terrestrial detritus and the carbon cycle." G. M. Woodwell and E. V. Pecan, ed. *Carbon and the biosphere*. Converence Proceedings 720510, U.S. Atomic Energy Commission.

Rheinhardt, R. D., Brinson, M. M., and Farley, P. M. (1997). "A preliminary reference data set for wet forested flats in North Carolina and its application to wetland functional assessment, mitigation, and restoration," *Wetlands* 17, 195-215.

Richardson, C. J. (1985). "Mechanisms controlling phosphorous retention capacity in freshwater wetlands," *Science* 228, 1424-27.

Ricklefs, R. E. (1990). *Ecology*, 3rd edition. W. H. Freeman and Company, New York.

Ritter, D. F., Kinsey, W. F., and Kauffman, M. E. (1973). "Overbank sedimentation in the Delaware river valley during the last 6000 years," *Science* 179, 374-75.

Ritter, D. F., Kochel, R. C., and Miller, J. R. (1995). *Process geomorphology*. 3rd ed. William C. Brown Publishers, Chicago, IL.

Robbins, C. S., Dawson, D. K., and Dowell, B. A. (1989). "Habitat area requirements of breeding forest birds of the middle Atlantic states," *Wildlife Monographs* 103, 1-34.

Robertson, P. A. (1992). "Environmental factors affecting tree growth on three wetland sites in southern Illinois," *American Midland Naturalist* 128, 218-326.

Robertson, P. A., MacKenzie, M. D., and Elliot, L. F. (1984). "Gradient analysis and classification of the woody vegetation for four sites in southern Illinois and adjacent Missouri," *Vegetation* 58, 87-104.

Robertson, P. A., Weaver, G. T., and Cavanaugh, J. A. (1978). "Vegetation and tree species patterns near the northern terminus of the southern floodplain forest," *Ecological Monographs* 48, 249-67.

Robinson, S. K. (1996). "Setting objectives in forested habitats." *Presentation, partners in flight, mid-west and southern Great Plains workshop*, April 8, 1996, St. Louis, MO.

Robinson, S. K., Thompson, F. R., III, Donovan, T. M., Whitehead, D. R., and Faaborg, J. (1995). "Regional forest fragmentation and the nesting success of migratory birds," *Science* 267, 1987-90.

Robinson, S. K., Grzybowski, J. A., Rothstein, S. I., Brittingham, M. C., Petit, L. J., and Thompson, F. R. (1993). "Management implications of cowbird parasitism on neotropical migrant songbirds." *Status and management of neotropical migratory birds*. D. M. Finch and P. W Stangel, ed., U S. Forest Service General Technical Report RM-229.

Rosgen, D. L. (1994). "A classification of natural rivers," *Catena* 22, 169-199.

__________. (1996). "Applied river morphology," *Wildland Hydrology*, Pagosa Springs, CO.

Ross, S. T., and Baker, J. A. (1983). "The response of fishes to periodic spring floods in a southeastern stream," *American Midland Naturalist* 109, 1-14.

Roulet, N. T. (1990). "Hydrology of a headwater basin wetland: Groundwater discharge and wetland maintenance," *Hydrological Processes* 4, 387-400.

Sallabanks, R., Walters, J. R., and Collazo, J. A. (1998). "Breeding bird abundance in bottomland forests: habitat, edge, and patch size effects," Auk: in review.

Schlesinger, W. H. (1977). "Carbon balance in terrestrial detritus," *Annual Review of Ecology and Systematics* 8, 51-81.

Schneider, D. C. (1994). *Quantitative ecology: Spatial and temporal scaling*. Academic Press, New York.

Schneider, R. L., and Sharitz, R. R. (1988). "Hydrochory and regeneration in a bald cypress water Tupelo swamp forest," *Ecology* 9, 1055-63.

Schoener, T. W. (1986). "Resource partitioning." *Community ecology: Patterns and processes*. J. Kikkawa and D. J. Anderson, ed., Blackwell, Melbourne, 91-126.

Schroeder, R. L. (1996a). "Wildlife community habitat evaluation: A model for deciduous palustrine forested wetlands in Maryland," Technical Report WRP-DE-14, U. S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

__________. (1996b). "Wildlife community habitat evaluation using a modified species-area relationship," Technical Report WRP-DE-12. U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Schroeder, R. L., O'Neil, L. J., and Pullen, T. M., Jr. "Wildlife community habitat evaluation: A model for bottomland hardwood forests of the southeastern United States," Technical Report in preparation, U. S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Scott, M. T., and Nielson, L. A. (1989). "Young fish distribution in backwaters and main channel borders of the Kanawha River, West Virginia," *Journal of Fish Biology* 35, 21-27.

Scott, V. E., Evans, K. E., Patton, D. R., and Stone, C. P. (1977). "Cavity nesting birds of North American forests," USDA Forest Service Handbook 553.

Sedell, J. R., Richey, J. E., and Swanson, F. J. (1989). "The river continuum concept: A basis for the expected ecosystem behavior of very large rivers," *Canadian Journal of Fisheries and Aquatic Science* 46, 49-55.

Sedell, J. R., Reeves, G. H., Hauer, F. R., Stanford, J. A., and Hawkins, C. P. (1990). "Role of refugia in recovery from disturbances: Modern fragmented and disconnected river systems," *Environmental Management* 14, 711-24.

Semeniuk, C. A. (1987). "Wetlands of the Darling System: A geomorphic approach to habitat classification," *Journal of the Royal Society of Western Australia* 69, 95-112.

Shafer, D. J., and Yozzo, D. J. (1998). "National guidebook for application of hydrogeomorphic assessment to tidal fringe wetlands," Technical Report WRP-DE-16, Wetlands Research Program, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Sharitz, R. R., and Mitsch, W. J. (1993). "Southern floodplain forests." *Biodiversity of the southeastern United States: Lowland terrestrial communities.* W. H. Martin, S. G. Boyce, and A. C. Echternacht, ed., John Wiley and Sons, New York, 311-72.

Shugart, H. H. (1987). "Dynamic ecosystem consequences of tree birth and death patterns," *BioScience* 37, 596-602.

Simberloff, D., Farr, J. A., Cox, J., and Mehlman, D. W. (1992). "Movement corridors: conservation bargains or poor investments?" *Conservation Biology* 6, 493-504.

Singh, J. S., and Gupta, S. R. (1977). "Plant decomposition and soil respiration in terrestrial ecosystems," *Botanical Review* 43, 449-528.

Smith, R. D. (1996). "Composition, structure, and distribution of woody vegetation on the Cache River floodplain, Arkansas," *Wetlands* 16, 264-78.

Smith, R. D., Ammann, A., Bartoldus, C., and Brinson, M. M. (1995). "An approach for assessing wetland functions using hydrogeomorphic classification, reference wetlands, and functional indices," Wetlands Research Program Technical Report WRP-DE-9, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Sorenson, T. A. (1948). "A method of establishing groups of equal amplitude in plant sociology based on similarity of species content, and its application to analyses of the vegetation on Danish commons," *Kongelige Danske Videnskabernes Selskab Biologiske Skrifter* 56, 1-34.

Spurr, S. H., and Barnes, B. V. (1981). *Forest ecology.* John Wiley and Sons, New York.

Stanford, J. A., Ward, J. V., Liss, W. J., Frissell, C. A., Williams, R. N., Lichatowich, J. A., and Coutant, C. C. (1996). "A general protocol for restoration of regulated rivers," *Regulated Rivers Research and Management* 12, 391-413.

Stauffer, D. F., and Best, L. B. (1980). "Habitat selection by birds of riparian communities evaluating effects of habitat alterations," *Journal of Wildlife Management* 44, 11-15.

Stewart, R. E., and Kantrud, H. A. (1971). "Classification of natural ponds and lakes in the glaciated prairie region," Resource Publication 92. U.S. Fish and Wildlife Service, Washington, DC.

Strahler, A. N. (1952). "Dynamic basis of geomorphology," *Geological Society of America Bulletin* 63, 923-38.

Suwong, S., Frayer, W. E., and Mogren, E. W. (1971). "Generalized comparisons of fixed radius and variable radius plots for basal area estimates," *Forest Sciences* 17, 263-71.

Symbula, M., and Day, F. W. (1988). "Evaluation of two methods for estimating belowground production in a fresh-water swamp forest," *American Midland Naturalist* 120, 405-15.

Szaro, R. C. (1980). "Factors influencing bird populations in the southwestern riparian forests." *Workshop proceedings: Management of western forests and grasslands for nongame birds*. R. M. DeGraaf, technical coordinator, U.S. Forest Service General Technical Report INT-86, 403-18.

Temple, S. A. (1986). "Predicting impacts of habitat fragmentation on forest birds: A comparison of two models." *Wildlife 2000: Modeling habitat relationships of terrestrial vertebrates*. J. Verner, M. L. Morrison and C. J. Ralph, ed., University of Wisconsin Press, Madison, WI, 301-04.

Temple, S. A., and Cary, J. R. (1988). "Modeling dynamics of habitat of forest interior bird populations in fragmented landscapes," *Conservation Biology* 2, 340-47.

ter Braak, C. J. F. (1994). "Canonical community ordination. Part 1: Basic theory and linear methods," *Ecoscience* 1, 127-140.

Thomas, D. M., and Hanson, M. A. (1981). "Generalization of streamflow characteristics from drainage-basin characteristics," Water Supply Paper 1-55, U. S. Geological Survey, Washington, DC.

Thompson, F. R., III, Dijak, W. D., Kulowiec, T. G., and Hamilton, D. A. (1992). "Breeding bird populations in Missouri Ozark forests with and without clearcutting," *Journal of Wildlife Management* 56, 23- 30.

Thompson, F. R., Robinson, S. K., Donovan, T. M., Faaborg, J., and Whitehead, D. R. (1998). "Biogeographic, landscape, and local factors affecting cowbird abundance and host parasitism levels." *Ecol-ogy and management of cowbirds*. T. Cook, S. Sealy, and J. N. M. Smith, ed., University of Texas Press, Austin (summarized in Robinson 1996).

Tinkle, D. W. (1959). "Observations of reptiles and amphibians in a Louisiana swamp," *American Mid-land Naturalist* 62, 189-205.

Tritton, L. M., and Hornbeck, J. W. (1982). "Biomass equations for major tree species the northeast," General Technical Report NE-69, U.S. Forest Service, Northeast Forest Experiment Station.

U.S. Army Corps of Engineers. (1981). "HEC-1 flood hydrograph package. Users manual," Hydrologic Engineering Center, Davis, CA.

__________. (1982). "HEC-2 water surface profiles. Users manual," Hydrologic Engineering Center, Davis, CA.

__________. (1997). "HEC- RAS river analysis system. User manual," Hydrologic Engineering Center, Davis, CA.

U.S. Department of Agriculture. (1977). "Soil survey for Hopkins County, Kentucky," Soil Conservation Service.

__________. (1980). "Soil survey for McLean and Muhlenberg Counties, Kentucky," Soil Conservation Service.

__________. (1987). "Soil survey for Ohio County, Kentucky," Soil Conservation Service.

U.S. Department of Agriculture. Natural Resources Conservation Service. (1977). "Chapter 19: Hydrology tools for wetland determination," Part 650, Engineering Field Handbook.

__________. (1996). "National soil survey handbook," Title 430-VI, U.S. Government Printing Office, Washington, DC.

U.S. Department of Agriculture. Natural Resources Conservation Service. (1998). "Field indicators of hydric soils in the United States, Version 4.0," Fort Worth, TX.

U.S. Department of Agriculture. Soil Conservation Service. (1993). "Soil survey manual," USDA Handbook 18, U.S. Government Printing Office, Washington, DC.

U.S. Environmental Protection Agency. (1983). "Freshwater wetlands for wastewater management; environmental impact statement," Report EPA 904/9-83-107, Region IV USEPA, Atlanta, GA.

U. S. Forest Service. (1980). "Wildlife habitat management handbook, southern region," FSH-2609.23R, U. S. Forest Service.

U.S. Water Resources Council. (1981). "Guidelines for determining flood flow frequency," Bulletin No. 17B, U. S. Water Resources Council, Washington, DC.

Vannote, R. L., Minshall, G. W., Cummins, K. W., Sedell, J. R., and Cushing, C. E. (1980). "The river continuum concept," *Canadian Journal of Fisheries and Aquatic Sciences* 37, 130-37.

Verpraskas, M. J. (1994). "Redoximorphic features for identifying aquatic conditions," Technical Bulletin 301, North Carolina Agricultural Research Service, North Carolina State University, Raleigh, NC.

Vogt, K. A., Grier, C. C., and Vogt, D. J. (1986). "Production, turnover, and nutrient dynamics of above and belowground detritus of world forests," *Advances in Ecological Research* 15, 303-77.

Wakeley, J. S., and Roberts, T. H. (1996). "Bird distribution and forest zonation in a bottomland hardwood wetland," *Wetlands* 16, 296-308.

Walling, D. E., Quine, T. A., and He, Q. (1992). "Investigating contemporary rates of floodplain sedimentation," *Lowland floodplain rivers: Geomorphological perspectives.* P. A. Carling and G. E. Petts, ed., John Wiley and Sons, New York.

Watson, I., and Burnett, A. D. (1993). *Hydrology: An environmental approach.* Buchanan Books, Ft. Lauderdale, FL.

Welcomme, R. L. (1979). *Fisheries ecology of floodplain rivers.* Longman, London.

Welsh, C. J. E., and Healy, W. M. (1993). "Effect of even-aged timber management on bird species diversity and composition in northern hardwoods of New Hampshire," *Wildlife Society Bulletin* 21, 143-54.

Wetlands Research Program. "Hydrogeomorphic approach to assessing wetland function: Guidelines for developing regional guidebooks," in preparation, Wetlands Research Program, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Wetzel, K. L., and Bettandorff, J. M. (1983). "Techniques for estimating streamflow characteristics in the eastern and interior coal provinces of the United States," Water-Supply Paper 2276, U.S. Geological Survey.

Wharton, C. H., Kitchens, W. M., Pendleton, E. C., and Sipe, T. W. (1982). "The ecology of bottomland hardwood swamps of the Southeast: A community profile," Office of Biological Services Report FWS/OBS-81/37. U. S. Fish and Wildlife Service, Washington, DC.

Wharton, C. H., Lambou, V. W., Newson, J., Winger, F. V., Gaddy, L. L., and Mancke, R. (1981). "The fauna of bottomland hardwoods in the southeastern United States." *Proceedings, workshop on bot-tomland hardwood forest wetlands of the southeastern United States.* J. R. Clark and J. Benforado, ed., Elsevier, New York, 87-160.

Whiles, M. R., and Grubaugh, J. W. (1993). "Importance of coarse woody debris to southern forest herpetofauna." *Biodiversity and coarse woody debris in southern forests.* J. W. McMinn and D. A. Crossley, ed., Southern Research Station GTR-SE-94, USDA Forest Service, 94-100.

Winter, T. C. (1976). "Numerical simulation analysis of the interaction of lake and ground water," U.S. Geological Survey Professional Paper 1001, U.S. Government Printing Office, Washington, DC.

__________. (1978). "Numerical simulation of steady state three-dimensional groundwater flow near lakes," *Water Resources Research* 14, 245-51.

Whittaker, R. H. (1975). *Communities and ecosystems*. MacMillan Publishing Company, New York.

Whittaker, R. H., Bormann, F. H., Likens, G. E., and Siccama, T. G. (1974). "The Hubbard Brook Ecosystem Study: forest biomass and production," *Ecological Monographs* 44, 233-54.

Wilcove, D. (1985). "Nest predation in forest tracts and the decline of migratory songbirds," *Ecology* 66, 1211-14.

Wotten, R. S. (1990). "The classification of particulate and dissolved matter." *The biology of particulates in aquatic systems*. R. S. Wotton, ed., CRC Press, Boca Raton, FL.

Yahner, R. H., and Scott, D. P. (1988). "Effects of forest fragmentation on depredation of artificial nests," *Journal of Wildlife Management* 52, 158-61.

Yarbro, L. A. (1983). "The influence of hydrologic variations on phosphorus cycling and retention in a swamp stream ecosystem." *Dynamics of lotic ecosystems*. T. D. Fontaine and S. M. Bartell, ed., Ann Arbor Science, Ann Arbor, MI, 223-46.

Yarbro, L. A., Kuenzler, E. J., Mulholland, P. J., and Sniffen, R. P. (1984). "Effects of stream channelization on exports of nitrogen and phosphorus from North Carolina coastal plain watersheds," *Environmental Management* 8, 151-60.

Zedler, P. H. (1987). "The ecology of southern California vernal pools: A community profile," Biological Report 85 (7.11), U.S. Fish and Wildlife Service, Washington, DC.

Appendix A Glossary

"A" horizon: A mineral soil horizon at the soil surface or below an "O" horizon characterized by accumulation of humified organic matter intricately mixed with the mineral fraction.

Assessment model: A simple model that defines the relationship between ecosystem and landscape scale variables and functional capacity of a wetland. The model is developed and calibrated using reference wetlands from a reference domain.

Assessment objective: The reason that an assessment of wetland functions is being conducted. Assessment objectives normally fall into one of three categories. These include: documenting existing conditions, comparing different wetlands at the same point in time (e.g., alternatives analysis), and comparing the same wetland at different points in time (e.g., impact analysis or mitigation success).

Assessment team (A-Team): An interdisciplinary group of regional and local scientists responsible for classification of wetlands within a region, identification of reference wetlands, construction of assessment models, definition of reference standards, and calibration of assessment models.

Channel: A natural stream or river, or an artificial feature, such as a ditch or canal, that exhibits features of bed and bank and conveys water primarily unidirectionally down gradient.

Direct impacts: Project impacts that result from direct physical alteration of a wetland, such as the placement of dredge or fill.

Direct measure: A quantitative measure of an assessment model variable.

Functional assessment: The process by which the capacity of a wetland to perform a function is measured. This approach measures capacity using an assessment model to determine a func-tional capacity index.

Functional capacity: The rate or magnitude at which a wetland ecosystem performs a function. Functional capacity is dictated by characteristics of the wetland ecosystem, the surrounding landscape, and the interaction between the two.

Functional capacity index (FCI): An index of the capacity of a wetland to perform a function relative to other wetlands from a regional wetland subclass in a reference domain. Functional capacity indices are by definition scaled from 0.0 to 1.0. An index of 1.0 indicates that a wetland performs a function at the highest sustainable functional capacity, the level equivalent to a wetland under reference standard conditions in a reference domain. An index of 0.0 indicates the wetland does not perform the function at a measurable level and will not recover the capacity to perform the function through natural processes.

Highest sustainable functional capacity: The level of functional capacity achieved across the suite of functions by a wetland under reference standard conditions in a reference domain. This approach assumes that the highest sustainable functional capacity is achieved when a wetland ecosystem and the surrounding landscape are undisturbed.

Hydrogeomorphic wetland class: The highest level in the hydrogeomorphic wetland classification. There are five basic hydrogeomorphic wetland classes, including depression, fringe, slope, riverine, and flat.

Hydrogeomorphic unit: Hydrogeomorphic units are areas within a wetland assessment area that are relatively homogeneous with respect to ecosystem scale characteristics such as microtopography, soil type, vegetative communities, or other factors that influence function. Hydrogeomorphic units may be the result of natural or anthropogenic processes. See **Partial wetland assessment area.**

Indicator: Indicators are observable characteristics that correspond to identifiable variable conditions in a wetland or the surrounding landscape.

Indirect measure: A qualitative measure of an assessment model variable that corresponds to an identifiable variable condition.

Indirect impacts: Impacts resulting from a project that occur concurrently, or at some time in the future, away from the point of direct impact. For example, indirect impacts of a project on wildlife can result from an increase in the level of activity in adjacent, newly developed areas, even though the wetland is not physically altered by direct impacts.

In-kind mitigation: Mitigation in which lost functional capacity is replaced in a wetland of the same regional wetland subclass.

Interflow: The lateral movement of water in the unsaturated zone during and immediately after a precipitation event. The water, moving as interflow, discharges directly into a stream or lake.

Jurisdictional wetland: Areas that meet the soil, vegetation, and hydrologic criteria described in the "Corps of Engineers Wetlands Delineation Manual" (Environmental Laboratory 1987), or its successor.

Mitigation: Restoration or creation of a wetland to replace functional capacity that is lost as a result of project impacts.

Mitigation plan: A plan for replacing lost functional capacity resulting from project impacts.

Mitigation wetland: A restored or created wetland that serves to replace functional capacity lost as a result of project impacts.

Model variable: A characteristic of the wetland ecocystem or surrounding landscape that influences the capacity of a wetland ecosystem to perform a function.

"O" horizon: A layer with more than 12 to 18 percent organic C (by weight; 50 percent by volume). Form of the organic material may be recognizable plant parts (Oi) such as leaves, needles, twigs, moss, etc., partially decomposed plant debris (Oe), or totally decomposed organic material (Oa) such as muck.

Off-site mitigation: Mitigation that is done at a location physically separated from the site at which the original impacts occurred, possibly in another watershed.

Out-of-kind mitigation: Mitigation in which lost function capacity is replaced in a wetland of a different regional wetland subclass.

Partial wetland assessment area (PWAA): A portion of a WAA that is identified *a priori,* or while applying the assessment procedure, because it is relatively homogeneous and different from the rest of the WAA with respect to one or more model variables. The difference may occur naturally or as a result of anthropogenic disturbance. See **Hydrogeomorphic unit**.

Project alternative(s): Different ways in which a given project can be done. Alternatives may vary in terms of project location, design, method of construction, amount of fill required, and other ways.

Project area: The area that encompasses all activities related to an ongoing or proposed project.

Project target: The level of functioning identified for a restoration or creation project. Conditions specified for the functioning are used to judge whether a project reaches the target and is developing toward site capacity.

Red flag features: Features of a wetland or the surrounding landscape to which special recognition or protection is assigned on the basis of objective criteria. The recognition or protection may occur at a Federal, State, regional, or local level and may be official or unofficial.
Reference domain: The geographic area from which reference wetlands are selected. A reference domain may, or may not, include the entire geographic area in which a regional wetland subclass occurs.

Reference standards: Conditions exhibited by a group of reference wetlands that correspond to the highest level of functional capacity (highest, sustainable level of functioning) across the suite of functions performed by the regional wetland subclass. The highest level of functional capacity is assigned an index value of 1.0 by definition.

Reference wetlands: Wetland sites that encompass the variability of a regional wetland subclass in a reference domain. Reference wetlands are used to establish the range of conditions for construction and calibration of functional indices and establish reference standards.

Region: A geographic area that is relatively homogeneous with respect to large scale factors such as climate and geology that may influence how wetlands function.

Regional wetland subclass: Wetlands within a region that are similar, based on hydrogeomorphic classification factors. There may be more than one regional wetland subclass identified within each hydrogeomorphic wetland class, depending on the diversity of wetlands in a region and the assessment objectives.

Site potential: The highest level of functioning possible, given local constraints of disturbance history, land use, or other factors. Site capacity may be equal to or less than levels of functioning established by reference standards for the reference domain, and it may be equal to or less than the functional capacity of a wetland ecosystem.

Throughflow: The lateral movement of water in an unsaturated zone during and immediately after a precipitation event. The water from throughflow seeps out at the base of slopes and then flows across the ground surface as return flow, ultimately reaching a stream or lake. See **Interflow** for comparison.

Value of wetland function: The relative importance of a wetland function to an individual or group.

Variable: An attribute or characteristic of a wetland ecosystem or the surrounding landscape that influences the capacity of the wetland to perform a function.

Variable condition: The condition of a variable as determined through quantitative or qualitative measure.

Variable index: A measure of how an assessment model variable in a wetland compares to the reference standards of a regional wetland subclass in a reference domain.

Wetland: See **Wetland ecosystem.**

Wetland ecosystems: In 404: ".......areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas" (Corps Regulation 33 CFR 328.3 and EPA Regulations 40 CFR 230.3). In a more general sense, wetland ecosystems are three dimensional segments of the natural world where the presence of water, at or near the surface, creates conditions leading to the development of redoxomorphic soil conditions, and the presence of a flora and fauna adapted to the permanently or periodically flooded or saturated conditions.

Wetland assessment area (WAA): The wetland area to which results of an assessment are applied.

Wetland banking: The process of creating a "bank" of created, enhanced, or restored wetland to serve at a future date as mitigation for project impacts.

Wetland functions: The normal activities or actions that occur in wetland ecosystems, or simply, the things that wetlands do. Wetland functions result directly from the characteristics of a wetland ecosystem and the surrounding landscape and their interaction.

Wetland creation: The process of creating a wetland in a location where a wetland did not previously exist. Wetland creation is typically done for mitigation.

Wetland enhancement: The process of increasing the capacity of a wetland to perform one or more functions. Wetland enhancement can increase functional capacity to levels greater than the highest sustainable functional capacity achieved under reference standard conditions, but usually at the expense of sustainability, or at a reduction of functional capacity of other functions. Wetland enhancement is typically done for mitigation.

Wetland restoration: The process of restoring wetland function in a degraded wetland. Restoration is typically done as mitigation.

Wetland values: See **Value of wetland functions**.

Appendix B
Summaries and Forms for Field Use

This appendix contains the following information summaries and example sheets:

Summary of Functions for Low Gradient, Riverine Wetlands

Function 1: Temporarily Store Surface Water

a. Definition. The function Temporarily Store Surface Water is defined as the capacity of a riverine wetland to temporarily store and convey floodwaters that inundate riverine wetlands during overbank flow events. The water that is stored and conveyed usually originates as overbank flows from an adjacent stream channel. However, other potential contributing sources of water include: (1) precipitation, (2) surface water from adjacent uplands transported to the wetland via surface channels or overland flow, and (3) subsurface water from adjacent uplands transported to the wetland as interflow or shallow groundwater and discharging at the edge, or interior, of the floodplain. A potential independent, quantitative measure for validating the functional index is the volume of water stored per unit area per unit time (m^3/ha/time) at a discharge that is equivalent to the average annual peak event.

b. Model variables - symbols - measures - units.

(1) Overbank flood frequency - V_{FREQ} - recurrence interval - years.

(2) Floodplain storage volume - V_{STORE} - floodplain width/channel width - unitless.

(3) Floodplain slope - V_{SLOPE} - change in elevation/prescribed distance along center line - unitless.

(4) Floodplain roughness - V_{ROUGH} - Manning's roughness coefficient *(n)* - unitless.

c. Assessment model:

$$FCI = \left[\left(V_{FREQ} \times V_{STORE} \right)^{1/2} \times \left(\frac{V_{SLOPE} + V_{ROUGH}}{2} \right) \right]^{1/2}$$

Function 2: Maintain Characteristic Subsurface Hydrology

a. Definition. Maintain Characteristic Subsurface Hydrology is defined as the capacity of a riverine wetland to store and convey subsurface water. Potential sources for subsurface water in riverine wetlands are direct precipitation, interflow (i.e., unsaturated subsurface flow), groundwater (i.e., saturated subsurface flow), and overbank flooding. A potential independent, quantitative measure for validating the functional index is the number of days each year that a characteristic depth to water table is maintained.

b. Model variables - symbols - measures - units:

(1) Subsurface water velocity - $V_{SOILPERM}$ - soil permeability - inches/hour.

(2) Water table slope - $V_{WTSLOPE}$ - percent of area being assessed with an altered water table slope - unitless.

(3) Subsurface storage volume - V_{PORE} - percent effective soil porosity - unitless.

(4) Water table fluctuation - V_{WTF} - presence/absence of fluctuating water table - unitless.

c. *Assessment model:*

$$FCI = \left[\frac{\left(V_{SOILPERM} \times V_{WTSLOPE}\right)^{1/2} + \left(\frac{V_{PORE} + V_{WTF}}{2}\right)}{2} \right]$$

Function 3: Cycle Nutrients

a. *Definition.* Cycling Nutrients is defined as the ability of the riverine wetland to convert nutrients from inorganic forms to organic forms and back, through a variety of biogeochemical processes such as photosynthesis and microbial decomposition. Potential independent, quantitative measures for validating the functional index include net annual primary productivity (gm/m^2), annual litter fall (gm/m^2), or standing stock of living and/or dead biomass (gm/m^2).

b. *Model variables - symbols - measures - units*:

(1) Tree biomass - V_{TBA} - tree basal area - m^2/ha.

(2) Understory vegetation biomass - V_{SSD} - density of understory woody stems - stems/ha.

(3) Ground vegetation biomass - V_{GVC} - percent cover of ground vegeta-tion - unitless.

(4) "O" horizon biomass - V_{OHOR} - percent cover of "O" soil horizon cover - unitless.

(5) "A" horizon biomass -V_{AHOR} - percent cover of "A" soil horizon - unitless.

(6) Woody debris biomass - V_{WD} - volume of woody debris - m^3/ha.

c. *Assessment model:*

$$FCI = \left[\frac{\left(\frac{V_{TBA} + V_{SSD} + V_{GVC}}{3}\right) + \left(\frac{V_{OHOR} + V_{AHOR} + V_{WD}}{3}\right)}{2} \right]$$

Function 4: Remove and Sequester Elements and Compounds

a. Definition. Removal and Sequestration of Elements and Compounds is defined as the ability of the riverine wetland to permanently remove or temporarily immobilize nutrients, metals, and other elements and compounds that are imported to the riverine wetland from upland sources and via overbank flooding. In a broad sense, elements include macro-nutrients essential to plant growth (nitrogen, phosphorus, and potassium) and other elements such as heavy metals (zinc, chromium, etc.) that can be toxic at high concentrations. Compounds include pesticides and other imported materials. The term "removal" means the permanent loss of elements and compounds from incoming water sources (e.g., deep burial in sediments, loss to the atmosphere), and the term "sequestration" means the short- or long-term immobilization of elements and compounds. A potential independent, quantitative measure of this function is the quantity of one or more imported elements and compounds removed or sequestered per unit area during a specified period of time (e.g., $g/m^2/yr$).

b. Model variables - symbols - measures - units:

(1) Overbank flood frequency - V_{FREQ} - recurrence interval - years

(2) Water table depth - V_{WTD} - depth to seasonal high water table - inches.

(3) Soil clay content -V_{CLAY} - percent difference of soil clay content - unitless.

(4) Redoximorphic features - V_{REDOX} - presence/absence of redoximorphic features - unitless.

(5) "O" horizon biomass - V_{OHOR} - percent cover of "O" soil horizon - unitless.

(6) "A" horizon biomass - V_{AHOR} - percent cover of "A" soil horizon - unitless

c. Assessment model:

$$FCI = \left[\left(\frac{V_{FREQ} + V_{WTD}}{2} \right) \times \left(\frac{V_{CLAY} + V_{REDOX} + V_{OHOR} + V_{AHOR}}{4} \right) \right]^{1/2}$$

Function 5: Retain Particulates

a. Definition. The Retain Particulates function is the capacity of a wetland to physically remove and retain inorganic and organic particulates (>0.45 μm) from the water column. Retention applies to particulates arising from both onsite and offsite sources. The quantitative measure of this function is the amount of particulates per unit area per unit time (e.g., $g/m^2/yr$).

b. Model variables - symbols - measures - units:

(1) Overbank flood frequency - V_{FREQ} - recurrence interval - years.

(2) Floodplain storage volume - V_{STORE} - floodplain width/channel width - unitless.

(3) Floodplain slope - V_{SLOPE} - change in elevation/prescribed distance along center line - unitless.

(4) Floodplain roughness - V_{ROUGH} - Manning's roughness coefficient *(n)* - unitless.

c. *Assessment model*:

$$FCI = \left[\left(V_{FREQ} \times V_{STORE} \right)^{1/2} \times \left(\frac{V_{SLOPE} + V_{ROUGH}}{2} \right) \right]^{1/2}$$

Function 6: Export of Organic Carbon

a. *Definition*. This function is defined as the capacity of the wetland to export dissolved and particulate organic carbon produced in the riverine wetland. Mechanisms include leaching of litter, flushing, displacement, and erosion. An independent quantitative measure of this function is the mass of carbon exported per unit area per unit time (e.g., $g/m^2/yr$).

b. *Model variables - symbols - measures - units*:

(1) Overbank flood frequency - V_{FREQ} - recurrence interval - years.

(2) Surface water connections - $V_{SURFCON}$ - percent of linear distance of altered stream reach - unitless.

(3) "O" horizon biomass - V_{OHOR} - percent cover of "O" soil horizon cover - unitless.

(4) Woody debris biomass - V_{WD} - volume of woody debris - m^3/ha.

c. *Assessment model:*

$$FCI = \left[\left(V_{FREQ} \times V_{SURFCON} \right)^{1/2} \times \left(\frac{V_{OHOR} + V_{WD}}{2} \right) \right]^{1/2}$$

Function 7: Maintain Characteristic Plant Community

a. *Definition.* Maintain Characteristic Plant Community is defined as the capacity of a riverine wetland to provide the environment necessary for a characteristic plant community to develop and be maintained. In assessing this function, one must consider both the extant plant community as an indication of current conditions and the physical factors that

determine whether or not a characteristic plant community is likely to be maintained in the future. Potential independent, quantitative measures of this function based on vegetation composition/abundance include similarity indices (Ludwig and Reynolds 1988)[1] or ordination axis scores from detrended correspondance analysis or other multivariate technique (Kent and Coker 1995). A potential independent quantitative measure of this function base on both vegetation composition/abundance and environmental factors is ordination axis scores from canonical correlation analysis (ter Braake 1994).

b. Model variables - symbols - measures - units:

(1) Tree biomass - V_{TBA} - tree basal area - m^2/ha.

(2) Tree density - V_{TDEN} - tree density - stems/ha.

(3) Plant species composition - V_{COMP} - percent concurrence with domi-nant species by strata - unitless.

(4) Overbank flood frequency - V_{FREQ} - recurrence interval - years.

(5) Water table depth - V_{WTD} - depth to seasonal high water table - inches.

(6) Soil integrity - $V_{SOILINT}$ - percent of area with altered soil - unitless.

c. Assessment model:

$$FCI = \left[\frac{\left(\frac{V_{TBA} + V_{TDEN}}{2}\right) + V_{COMP}}{2} \times \frac{V_{SOILINT} + V_{FREQ} + V_{WTD}}{3} \right]^{1/2}$$

Function 8: Provide Habitat for Wildlife

a. Definition. The function Provide Habitat for Wildlife reflects the ability of a riverine wetland to support the wildlife species that utilize riverine wetlands during some part of their life cycles. The focus of this model is on avifauna, based on the assumption that, if conditions are appropriate to support the full complement of avian species found in reference standard wetlands, the requirements of other animal groups (e.g., mammals, reptiles, and amphibians) will be met. A potential independent, quantitative measure of this function is a similarity index calculated from species composition and abundance (Odum 1950, Sorenson 1948).

b. Model variables - symbols - measures - units:

(1) Overbank flood frequency - V_{FREQ} - recurrence interval - years.

[1] References cited in this appendix are listed in the References at the end of the main text.

(2) Macrotopographic features - V_{MACRO} - percent of area with macrotopographic features - unitless.

(3) Plant species composition - V_{COMP} - percent concurrence with dominant species by strata - unitless.

(4) Tree biomass - V_{TBA} - tree basal area - m^2/ha.

(5) Tree density - V_{TDEN} - tree density - stems/ha.

(6) Log biomass - V_{LOG} - volume of logs - m^3/ha.

(7) Snag density - V_{SNAG} - snag density - stems/ha.

(8) "O" horizon biomass - V_{OHOR} - percent cover of "O" soil horizon cover - unitless.

(9) Wetland tract - V_{TRACT} - size of wetland tract - ha.

(10) Interior core area - V_{CORE} - percent of wetland tract with 100-m buffer - unitless.

(11) Habitat connections - $V_{CONNECT}$ - percent of wetland tract perimeter connected - unitless.

c. *Assessment model*:

$$FCI = \left[\frac{\left(\frac{V_{FREQ} + V_{MACRO}}{2}\right) + \left(\frac{V_{TRACT} + V_{CONNECT} + V_{CORE}}{3}\right)}{2} \times \frac{V_{COMP} + V_{TBA} + V_{TDEN} + V_{SNAG} + \left(\frac{V_{LOG} + V_{OHOR}}{2}\right)}{5} \right]^{1/2}$$

Summary of Model Variables, Measure/Units, and Methods

1. Wetland tract (V_{TRACT})

Measure/Units: The area of wetland in hectares that is contiguous with the WAA and of the same regional wetland subclass.

Method: (1) Determine the size of the area of wetland of the same regional subclass that is contiguous with the assessment area using field reconnaissance, topographic maps, National Wetland Inventory maps (NWI), or aerial photography.

(2) Report the size of the wetland tract in hectares.

2. Interior core area (V_{CORE})

Measure/Units: The percent of the wetland tract with a buffer zone >100 m separating it from nonforested habitat.

Method:

(1) Determine the area of the wetland tract within a buffer of at least 300 m using field reconnaissance, topographic maps, NWI maps, aerial photography, or other sources.

(2) Divide the area of the wetland within the buffer by the total size of the wetland tract and multiply by 300. The result is the percentage of the wetland tract within a buffer zone >300 m.

(3) Report the size of the area within a 300-m buffer as a percentage of total tract area.

3. Habitat connections ($V_{CONNECT}$)

Measure/Units: The percent of the perimeter of the wetland tract that is "connected" to the total length of the perimeter of the wetland.

Method:

(1) Determine the total length of the wetland perimeter using field reconnaissance, topographic maps, or aerial photography.

(2) Determine the length of the wetland perimeter that is "connected" to suitable habitats such as other wetlands, upland forests, or other wildlife habitats.

(3) Divide the length of "connected" wetland perimeter by the total length of the wetland perimeter.

(4) Convert to a percent of the perimeter by multiplying by 100.

(5) Report as the percent of the perimeter of the wetland tract that is "connected"

4. Floodplain slope (V_{SLOPE})

Measure/Units: Percent floodplain slope.

Method:

(1) Determine the change in elevation between two points along the floodplain center line (i.e, center line of the meander belt of the active channel) on a river reach representative of the area being assessed (Figure 8, main text). This can be accomplished using the contour lines on a standard 7.5-minute USGS topographic map. The distance between the two points should be great enough so that local anomalies in floodplain slope do not influence the result. As a rule of thumb, the line between the two points should intersect at least two contour lines on a 1:24,000 scale (7.5-minute) USGS topo map.

(2) Determine the distance between the two points.

(3) Divide the change in elevation by the distance between the two points. For example, if the change in elevation between the two points is 10 ft (3 m) and the distance between the two points is 1 mile (5,280 ft) (1,609 m) the slope is 10 ft/5,280 ft = 0.002 (3m/1,609 m = 0.002) .

(4) Convert the slope to a percent slope by multiplying by 100.

(5) Report floodplain slope as a percent.

5. Floodplain storage volume (V_{STORE})

Measure/Units: The ratio of floodplain width to channel width (i.e., floodplain width/channel width).

Method: (1) Measure the width of the floodplain and the width of the channel using surveying equipment or by pacing in the field (Figure 6, main text). A crude estimate can be made using topographic maps, or aerial photos, remembering that short distances on maps and photographs translate into long distances on the ground (e.g., a section line on a 1:24,000 USGS topographic map represents about 30 ft (9.1 m) on the ground).

(2) Calculate the ratio by dividing the floodplain width by the channel width.

(3) Report the ratio of floodplain width to channel width as a unitless number.

6. Macrotopographic features (V_{MACRO})

Measure/Units: The percent of the WAA occupied by macrotopographic features.

Method: (1) If the area being assessed is greater than 1 km^2, the percentage of the area that consists of macrotopographic features is used to quantify this variable. Measure it with the procedure outlined under Alternative 1 if the area being assessed is greater than 1 km^2 or Alternative 2 if the area is less than 1 km^2.

(a) Alternative 1: Based on field reconnaissance, topographic maps, and aerial photographs, estimate the areal extent of the macrotopographic features in the assessment area.

(b) Alternative 2: Based on field reconnaissance, topographic maps, and aerial photographs, estimate the areal extent of the macrotopographic features in a 1-km^2 area around the assessment area. For instance, a 1-km^2 template can be placed on a map or aerial photograph of appropriate scale and the percentage of that area covered by macrotopographic features can be estimated.

(2) Report the percentage of the area being assessed that is covered with macro-topographic features.

7. Overbank flood frequency (V_{FREQ})

Measure/Units: Recurrence interval in years.

Method: (1) Use one of the following methods to determining recurrence interval with the guidelines provided in Appendix C:

(a) Data from a nearby stream gage;

(b) Regional flood frequency curves developed by local and State offices of USACE, USGS-Water Resources Division, State Geologic Surveys, or NRCS (Jennings, Thomas, and Riggs 1994);

(c) Hydrologic models such as HEC-2 (U.S. Army Corps of Engineers 1981, 1982), HECRAS (U.S. Army Corps of Engineers 1997), HSPF (Bicknell et al. 1993);

(d) Local knowledge; or

(e) Regional dimensionless rating curve (Pruitt and Nutter unpublished manuscript).

(2) Report recurrence interval in years.

8. Floodplain roughness (V_{ROUGH})

Measure/Units: Manning's roughness coefficient (n).

Method: (1) Alternative 1 (not recommended): Compare the area to be assessed to the photographs of forested floodplains presented in Arcement and Schneider (1989). These photographs illustrate a variety of conditions for which Manning's roughness coefficient has been calculated empirically and can be used in the field to estimate Manning's roughness coefficient for sites that are well stocked with trees.

(2) Alternative 2: Use Arcement and Schneider's (1989) method for estimating Manning's roughness coefficient based on a characterization of the different components that contribute to roughness on floodplains which include: micro- and macrotopographic relief (n_{TOPO}), obstruction (n_{OBS}), and vegetation (n_{VEG}). Complete the following steps:

(a) Determine the value of n_{BASE} (i.e., the contribution to roughness of bare soil). Arcement and Schneider (1989) suggest using 0.03, the value for firm soil.

(b) Using the descriptions in Table B1, assign an adjustment value to the roughness components of n_{TOPO}, n_{OBS}, and n_{VEG}.

(c) Sum the values of the roughness components.

Table B1
Adjustment Values for Roughness Components

Roughness Component	Adjustment to *n* value	Description of Conditions
Topographic relief (n_{TOPO})	0.0	Representative area is flat with essentially no microtopographic relief (i.e., hummocks or holes created by tree fall) or macrotopographic relief (i.e., ridges and swales).
	0.005	Microtopographic relief (i.e., hummocks or holes created by tree fall) or macrotopographic relief (i.e., ridges and swales) covers 5-25% of a representative area.
	0.01	Microtopographic relief (i.e., hummocks or holes created by tree fall) or macrotopographic relief (i.e., ridges and swales) covers 26-50% of a representative area.
	0.02	Microtopographic relief (i.e., hummocks or holes created by tree fall) or macrotopographic relief (i.e., ridges and swales) covers >50% of a representative area.
Obstructions (n_{OBS}) (includes coarse woody debris, stumps, debris deposits, exposed roots)	0.0	No obstructions present
	0.002	Obstructions occupy 1-5% of a representative cross-sectional area.
	0.01	Obstructions occupy 6-15% of a representative cross-sectional area.
	0.025	Obstructions occupy 16-50% of a representative cross- sectional area.
	0.05	Obstructions occupy >50% of a representative cross-sectional area.
Vegetation (n_{VEG})	0.0	No vegetation present
	0.005	Representative area covered with dense herbaceous or woody vegetation where depth of flow exceeds height of vegetation by 3 times.
	0.015	Representative area covered with dense herbaceous or woody vegetation where depth of flow exceeds height of vegetation by by 2-3 times.
	0.05	Representative area covered with herbaceous or woody vegetation where depth of flow is at height of vegetation.
	0.1	Representative area fully stocked with trees and with sparse herbaceous or woody understory vegetation.
	0.15	Representative area partially to fully stocked with trees and with dense herbaceous or woody understory vegetation.

(3) Report Manning's roughness coefficient *(n)* as a unitless number.

9. Soil integrity ($V_{SOILINT}$)

Measure/Units: The percent of the WAA with altered soils.

Method:

(1) Determine if any of the soils in the area being assessed have been altered. In particular look for alteration to a normal soil profile. For example, absence of an "A" horizon, presence of fill material, or other types of impact that significantly alter soil integrity.

(2) If no altered soils exist, assign the variable subindex a value of 1.0. This indicates that all of the soils in the assessment area are similar to soils in reference standard sites.

(3) If altered soils exist, determine what percent of the assessment area has soils that have been altered.

(4) Report the percent of the assessment area with altered soils.

10. Water table fluctuation (V_{WTF})

Measure/Units: Presence or absence of a fluctuating water table.

Method:

(1) Determine the presence or absence of a fluctuating water table using the following (in order of accuracy and preference):

(a) Monitored groundwater well data;

(b) Redoximorphic features such as oxidized rhizospheres, reaction to *a, a'* dipyridyl, or the presence of a reduced soil matrix (Verpraskas 1994, Hurt et al. 1996), remembering that some redoximorphic features reflect that a soil has been anaerobic at some time in the past but do not necessarily reflect current conditions;

(c) The presence of a fluctuating seasonal high water table according to the Soil and Water Features Table in modern County Soil Surveys. In situations where the fluctuation of the water table has been altered as a result of raising the land surface above the water table through the placement of fill, the installation of drainage ditches, or drawdown by water supply wells, the information in the Soil Survey is no longer useful. Under these circumstances, the use of well data or redoximorphic features that indicate current conditions may be the only way to obtain the necessary information.

(2) Report fluctuating water table as present or absent.

11. Water table depth (V_{WTD})

Measure/Units: Depth to the seasonal high water table in inches.

Method:

(1) Determine the depth to the seasonal high water table using the following (in order of accuracy and preference):

(a) Monitored groundwater well data;

(b) Redoximorphic features such as oxidized rhizospheres, reaction to *a, a'* dipyridyl, or the presence of a reduced soil matrix (Verpraskas 1994, Hurt et al. 1996), remembering that some redoximorphic features reflect that a soil has been anaerobic at some time in the past but do not necessarily reflect current conditions;

(c) The presence of a fluctuating seasonal high water table according to the Soil and Water Features Table in modern County Soil Surveys. In situations where the fluctuation of the water table has been altered as a result of raising the land surface above the water table through the placement of fill, the installation of drainage ditches, or drawdown by water supply wells, the information in the Soil Survey is no longer useful. Under these circumstances, the use of well data or redoximorphic features that indicate current conditions may be the only way to obtain the necessary information.

(2) Report the depth to the seasonal high water table in inches.

12. Water table slope ($V_{WTSLOPE}$)

Measure/Units: The percent of the WAA with an altered water table slope.

Method:

(1) Determine if the slope of the ground surface has been altered, by ditching, tiling, dredging, channelization, or other activities with the potential to modify the water table slope.

(2) If the slope of the water table has not been altered the percent of the area altered is 0.0.

(3) If the water table slope has been altered in any portion of the area being assessed, determine the soil type and the "depth of the alteration." For example, if the ditch has been dug, the depth of the alteration is the depth of the ditch measured from the original ground surface (Figure 13, main text). If a stream channel has been dredged, the depth of the alteration is the difference between the old and new channel depth.

(4) Use Table B2 to determine the lateral distance that will be affected by the alteration. For example, if the soil is in the Belknap series and the depth of the

Table B2
Lateral Effect of Ditches

Soil Series	Depth of Ditch or Change in Depth of Channel, ft							
	3	4	5	6	7	8	9	10
Belknap	91 (300)	132 (434)	166 (544)	196 (642)	223 (732)	249 (818)	274 (900)	299 (980)
Bonnie	72 (235)	104 (341)	130 (427)	153 (503)	175 (574)	196 (642)	215 (706)	234 (769)
Karnak	48 (156)	69 (225)	86 (282)	101 (333)	116 (380)	129 (424)	142 (467)	155 (509)
McGary	87 (284)	125 (410)	157 (514)	185 (606)	211 (692)	236 (773)	259 (851)	282 (926)
Melvin	129 (424)	187 (614)	234 (769)	277 (908)	316 (1036)	353 (1157)	388 (1273)	422 (1386)
Newark	129 (424)	187 (614)	234 (769)	277 (908)	316 (1036)	353 (1157)	388 (1273)	422 (1386)
Nolin	129 (424)	187 (614)	234 (769)	277 (908)	316 (1036)	353 (1157)	388 (1273)	422 (1386)
Steff	129 (424)	187 (614)	234 (769)	277 (908)	316 (1036)	353 (1157)	388 (1273)	422 (1386)
Stendal	129 (424)	187 (614)	234 (769)	277 (908)	316 (1036)	353 (1157)	388 (1273)	422 (1386)
Waverly	129 (424)	187 (614)	234 (769)	277 (908)	316 (1036)	353 (1157)	388 (1273)	422 (1386)
Zipp	72 (236)	104 (341)	130 (427)	154 (504	175 (575)	196 (643)	215 (707)	235 (770)

alteration is 5 ft (1.5 m) the lateral ditch effect is 544 ft (165.8 m). The procedures used to calculate the values in this table are based on the Ellipse Equation (USDA NRCS 1977) described in Appendix C.

(5) Using the lateral distance of the effect and the length of the alteration, estimate the size of the area that will be affected by the alteration. For example, if the lateral effect of the ditch is 544 ft (165.8 m) and the ditch is 50 ft (15.2 m) long, the area affected is $544 \times 50 = 27{,}200$ ft^2 (0.62 acres) (0.25 ha).

(6) Calculate the ratio of the size of all areas within the area being assessed that are affected by an alteration to the water table slope to the size of the entire area being assessed. For example, if the area affected by the alteration is 0.62 acres (0.25 ha), and the area being assessed is 10 acres (4 ha), the ratio is $0.62 / 10 = 0.062$ ($0.25/4 = 0.062$).

(7) Multiply the ratio by 100 to obtain the percentage of the area being assessed with an altered water table slope.

(8) Report the percent of the area being assessed with an altered water table slope.

13. Subsurface water velocity ($V_{SOILPERM}$)

Measure/Units: Soil permeability in inches per hour.

Method: (1) Determine if soils in the area being assessed have been altered by agricultural activity, silvicultural activity, placement of fill, use of heavy equipment in con-

struction projects or surface mining, or any other activities with the potential to alter effective soil permeability.

(2) If soils have been altered, select one of the two following alternatives, otherwise skip this step.

(a) Assign a value to soil permeability based on a representative number of field measurements of soil permeability. The number of measurements will depend on how variable and spatially heterogeneous the effects of the alteration are on soil properties. Appendix C provides a procedure for measuring soil permeability in the field using a "pumping test" in which water is pumped quickly from a groundwater well and the rate at which the water level recovers is measured (Freeze and Cherry 1979).

(b) Assign a variable subindex based on the category of alteration that has occurred at the site using the information in Table B3. (Note: in this particular situation no value is assigned to soil permeability, rather, a variable subindex is assigned directly).

Table B3
Variable Subindices for Altered Soils

Alteration Category	"Typical" Soil Permeability After Alteration	Average Depth of Alteration Effects	Variable Subindex
Silviculture: normal activities compact surface layers and reduce permeability to a depth of about 6 in. (Aust 1994)	highly variable and spatially heterogeneous	top 6 in. of soil profile	0.7
Agricultural Tillage: some surface compaction occurs as well as generally decreasing the average size of pore spaces which decreases the ability of water to move through the soil to depth of about 6 in. (Drees et al. 1994).	highly variable and spatially heterogeneous	top 6 in. of soil profile	0.7
Construction Activities / Surface Mining: compaction resulting from large equipment over the soil surface, cover of soil surface with pavement or fill material, or excavation and subsequent replacement of heterogeneous materials	highly variable and spatially heterogeneous	entire soil profile	0.1

(3) If the soils have not been altered, select one of the two following alternatives.

(a) Assign a value to soil permeability based on a representative number of field measures of soil permeability. The number of field measures will depend on how variable and spatially heterogeneous the effects of the alteration are on soil properties. Appendix C provides a procedure for measuring soil permeability in the field using a "pumping test" in which water is pumped quickly from a groundwater well and the rate at which the water level recovers is measured (Freeze and Cherry 1979).

(b) Assign a value to soil permeability by calculating the weighted average of median soil permeability to a depth of 20 in. Information for the soil

series that occur in western Kentucky riverine wetlands is in Table B4. Calculate the weighted average of median soil permeability by averaging the median soil permeability values to a depth of 20 in. For example, in Table B4, the Karnak series has a median soil permeability value from a depth of 0-5 in. of 0.4, and a median soil permeability value from a depth of 6-20 in. of 0.2. Thus, the weighted average of the median soil permeability for the top 20 in. is $((5 \times 0.4) + (15 \times 0.2)) / 20 = 0.25$.

Table B4
Soil Permeability at Different Depths for Soil Series in Western Kentucky

Soil Series	Depth, in.	Range of Soil Permeability, in./hr	Weighted Average Soil Permeability in top 20 in., in./hr
Belknap	0-20	0.6-2.0	1.3
Bonnie	0-20	0.2-0.6	0.4
Karnak	0-5 / >5-20	0.2-0.6 / <0.2	0.25
McGary	0-8 / >8-20	0.6-2.0 / <0.2	0.64
Melvin	0-20	0.6-2.0	1.3
Newark	0-20	0.6-2.0	1.3
Nolin	0-20	0.6-2.0	1.3
Steff	0-20	0.6-2.0	1.3
Stendal	0-20	0.6-2.0	1.3
Waverly	0-20	0.6-2.0	1.3
Zipp	0-10 / >10-20	0.2-2.0 / 0.06-0.2	0.62

(4) Report soil permeability in inches/hour.

14. Subsurface storage volume (V_{PORE})

Measure/Units: Percent effective soil porosity is the measure of this variable.

Method: (1) Determine if soils in the area being assessed have been altered by agricultural activity, silvicultural activity, placement of fill, use of heavy equipment in construction projects or surface mining, or any other activities with the potential to alter effective soil permeability.

(2) If soils have been altered:

(a) Assign a value to soil permeability based on a representative number of field measures of soil bulk density. The number of field measures will depend on how variable and spatially heterogeneous the effects of the alteration are on soil properties. Appendix C provides a procedure for using measurements of bulk density to determine effective soil porosity.

(b) Assign a variable subindex based on the category of alteration that has occurred at the site shown in Table B3. (Note: in this particular situation, no value is assigned to the metric, rather, a variable subindex is assigned directly).

(3) If the soils have not been altered, quantify percent effective soil porosity using one of the following options.

(a) Collect a representative number of field measures of bulk density and use the procedure outlined in Appendix C to determine percent effective soil porosity. The number of field measures of bulk density will depend on how variable and spatially heterogeneous the effects of the alteration are on soil properties.

(b) Use the percent effective soil porosity values for particular soil series provided in Table B5. The procedures used to calculate the values in this table are provided in Appendix C.

Table B5
Soil Series and Effective Soil Porosity Values

Soil Series	Median Bulk Density, g/cm^3	Total Porosity, %	Residual Water Content, %	Effective Soil Porosity, %	Soil Texture
Belknap	1.45	45	1.5	43.5	SiL
Bonnie	1.4	47	4.0	43.0	SiCL
Karnak	1.3	51	5.6	45.4	SiC
McGary	1.5	44	4.0	40.0	SiCL
Melvin	1.4	48	1.5	46.5	SiL
Newark	1.3	51	2.8	48.2	SiL, SiCL
Nolin	1.34	49	2.8	46.2	SiL, SiCL
Steff	1.4	47	2.8	44.2	SiL,SiCL
Stendal	1.47	45	1.5	43.5	SiL
Waverly	1.45	45	1.5	43.5	Si,SiL
Zipp	1.47	45	7.5	37.5	SiC, C

(4) Report subsurface storage volume as percent effective soil porosity.

15. Surface water connections ($V_{SURFCON}$)

Measure/Units: The percent of the linear distance of stream reach adjacent to the WAA that has been altered is the measure of this variable.

Method: (1) Conduct a visual reconnaissance of the WAA and the adjacent stream reach. Estimate what percent of this stream reach has been modified with levees, side

cast materials, or other obstructions that reduce the exchange of surface water between the stream channel and the riverine wetland.

(2) Report percent of the linear distance of the stream reach that has been altered.

16. Soil clay content (V_{CLAY})

Measure/Units: The difference in clay content in the top 20 in. (50.8 cm) of the soil profile in the WAA is used to quantify this variable.

Method: (1) Determine if the native soil in any of the area being assessed has been covered with fill material, excavated and replaced, or subjected to any other types of impact that significantly change the clay content of the top 20 in. (50.8 cm) of the soil profile. If no such alteration has occurred, assign the variable subindex a value of 1.0 and move on to the next variable. A value of 1.0 indicates that none of the soils in the area being assessed have an altered clay content in the top 20 in. (50.8 cm).

(2) If the soils in the part of the area being assessed have been altered in one of the ways described above, estimate the soil texture for each soil horizon in the upper 20 in. (50.8 cm) in representative portions of these areas. Soil particle size distribution can be measured in the laboratory on samples taken from the field, or the percent of clay can be estimated from field texture determinations done by the "feel" method. Appendix C describes the procedures for estimating texture class by feel.

(3) Based on the soil texture class determined in the previous step, the percentage of clay is determined from the soil texture triangle. The soil texture triangle contains soil texture classes and the corresponding percentages of sand, silt, and clay that comprise each class. Once the soil texture is determined by feel, the corresponding clay percentage is read from the left side of the soil texture triangle. The median value from the range of percent clay is used to calculate the weighted average. For example, if the soil texture at the surface were a silty clay loam, the range of clay present in that texture class is 28-40 percent. A median value of 34 percent would be used for the clay percentage in that particular horizon.

(4) Calculate a weighted average of the percent clay in the altered soil by averaging the percent clay from each of the soil horizons to a depth of 20 in. (50.8 cm). For example, if the "A" horizon occurs from a depth of 0-5 in. (0-12.7 cm) and has 30 percent clay, and the B horizon occurs from a depth of 6-20 in. (15.2-50.8 cm) and has 50 percent clay, then the weighted average of the percent clay for the top 20 in. (50.8 cm) of the profile is ((5 × 30) + (15 × 50)) / 20 = 45 percent.

(5) Calculate the difference in percent clay between the natural soil (i.e., what existed prior to the impact) and the altered soil using the following formula: percent difference = ((| percent clay after alteration - % clay before alteration

|) / % clay before alteration). For example, if the percent clay after alteration is 40 percent, and the percent clay before alteration is 70 percent, then | 40 - 70 | = 30, and (30 / 70) = 43 percent.

(6) Average the results from representative portions of the altered area.

(7) Multiply the percent difference for each altered area by the percent of the riverine wetland being assessed that the area represents (Column 3 in Table B6).

Table B6
Calculating Percent Difference of Clay in Soils of WAA

Area Description	Average Percent Difference in Clay Content in the Area	Percent of Area Being Assessed Occupied by the Area	Column 2 × Column 3
Altered Area 1	43% (0.43)	10% (0.10)	0.043
Altered Area 2	50% (0.50)	10% (0.10)	0.05
Unaltered Area	0.0% (0)	80% (0.80)	0
Percent difference = (sum of column 4) × 100 = 9.3 %			0.093

(8) Sum values in Column 4 and multiply by 100 to obtain the percent difference (last row in Table B6).

(9) Report the percent difference in the soil clay content in the area being assessed.

17. Redoximorphic features (V_{REDOX})

Measure/Units: The presence or absence of redoximorphic features is the measure of this variable.

Method: (1) Observe the top 20 in. (50.8 cm) of the soil profile and determine if redoximorphic features, accumulation or organic matter, or other hydric soil indicators are present or absent.

(2) Report redoximorphic features as present or absent.

18. Tree biomass (V_{TBA})

Measure/Units: Tree basal area in square meters per hectare is the measure of this variable.

Method: (1) Measure the dbh in centimeters of all trees in a circular 0.04-ha sampling unit (Pielou 1984), hereafter called a plot.

(2) Convert each of the diameter measurements to area, sum them, and then convert to square meters. For example, if 3 trees with diameters of 20 cm, 35 cm, and

22 cm were present in the plot, the conversion to square meters would be made as follows. Remembering that the diameter of a circle (D) can be con-verted to area (A) using the relationship $A = 1/4\pi D^2$, it follows that $1/4\pi 20^2 = 314$ cm^2, $1/4\pi 35^2 = 962$ cm^2, $1/4\pi 22^2 = 380$ cm^2. Summing these values gives 314 + 962 + 380 = 1,656 cm^2 and converting to square meters by multiplying by 0.0001 gives 1,656 cm^2 $\times$ 0.0001 = 0.17 m^2. Not many trees in that plot!

(3) If multiple 0.04-ha plots are sampled, average the results from all plots.

(4) Convert the results to a per hectare basis by multiplying by 25, since there are 25 0.04-ha plots in a hectare. For example, if the average value from all the sampled plots is 0.17 m^2, then 1.7 m^2 $\times$ 25 = 4.3 m^2/ha. A pretty sparse "forest"!

(5) Report tree basal area in square meters per hectare.

19. Tree density (V_{TDEN})

Measure/Units: The number of tree stems per hectare.

Method:

(1) Count the number of tree stems in a circular 0.04-ha plot.

(2) If multiple 0.04-ha plots are sampled, average the results from all plots. The number of 0.04-ha plots required to adequately characterize the area being assessed will depend on its size and heterogeneity.

(3) Convert the results to a per hectare basis by multiplying by 25. For example, if the average value from all the sampled plots is 20 stems, then 20 $\times$ 25 = 500 stems/ha.

(4) Report tree density in stems/hectare.

20. Snag density (V_{SNAG})

Measure/Units: The number of snag stems per hectare.

Method:

1. Count the number of snag stems in a circular 0.04 plot.
2. If multiple 0.04-ha plots are sampled, average the results from all plots. The number of 0.04-ha plots required to adequately characterize the area being assessed will depend on its size and heterogeneity.
3. Convert the results to a per hectare basis by multiplying by 25. For example, if the average value from all the sampled plots is 2 stems, then 2 $\times$ 25 = 50 stems/ha.
4. Report the number of snags as stems per hectare.

21. Woody debris biomass (V_{WD})

Measure/Units: Volume of woody debris in cubic meters per hectare is the measure of this variable.

Method: (1) Count the number of stems that intersect a vertical plane along a minimum of two transects located randomly and at least partially inside a 0.04-ha plot. Count the number of stems in each of three different size classes along the transect distance prescribed below. A 6-ft transect is used to count stems ≥ 0.25 to ≤ 1.0 in. in diameter, a 12-ft transect interval is used to count stems >1 to ≤ 3 in. in diameter, and a 50-ft transect is used to count stems >3 in. in diameter.

(2) Convert stem counts for each size class to tons per acre using the following formulas. For stems in the ≥ 0.25- to ≤ 1.0-in. and >1- to ≤ 3-in. size classes use the formula:

$$tons\,/\,acre = \frac{(11.64 \times n \times d^2 \times s \times a \times C)}{N \times l}$$

where

n = total number of intersections (i.e., counts) on all transects

d^2 = squared average diameter for each size class

s = specific gravity (Birdsey (1992) suggests a value of 0.58)

a = nonhorizontal angle correction (suggested value: 1.13)

C = slope correction factor (suggested valued: 1.0, since slopes in southeastern forested floodplains are negligible)

N = number of transects

l = total length of transects in feet

For stems in the >3-in. size class, use the following formula:

$$tons\,/\,acre = \frac{(11.64 \times \sum d^2 \times s \times a \times C)}{N \times l}$$

where

$\sum d^2$ = the sum of the squared diameter of each intersecting stem

When inventorying large areas with many different tree species, it is practical to use composite values and approximations for diameters, specific gravities, and nonhorizontal angle corrections. For example, if composite average diameters, composite average nonhorizontal correction factors, and best approximations for specific gravities are used for the Southeast, the preceding formula for stems in the 0.25-1.0 in. size class simplifies to:

$$tons \,/\, acre = \frac{2.24(n)}{N \times l}$$

For stems in the >1.0- 3.0 in. size class the formula simplifies to:

$$tons \,/\, acre = \frac{21.4(n)}{N \times l}$$

For stems in the >3.0 in. size class the formula simplifies to:

$$tons \,/\, acre = \frac{6.87(\sum d^2)}{N \times l}$$

(3) Convert tons per acre to cubic feet per acre using the formula:

$$Cubic\ feet \,/\, acre = \frac{tons \,/\, acre \times 32.05}{0.58}$$

(4) Convert cubic feet per acre to cubic meters per ha by multiplying by 0.072.

(5) Report woody debris volume in cubic meters per hectare.

22. Log biomass (V_{LOG})

Measure/Units: Volume of logs in cubic meters per hectare is the measure of this variable.

Method: (1) Use the volume of logs calculated for woody debris biomass (V_{WD}).

(2) Report log volume in cubic meters per hectare.

23. Understory vegetation biomass (V_{SSD})

Measure/Units: Stem density in number of stems per hectare.

Method:

(1) Count the stems of understory vegetation in either a 0.04-ha plot, or each of four 0.004-ha sampling units, hereafter called subplots, located in representative portions of each quadrant of the 0.04-ha plot. Sample using four 0.004-ha subplots if the stand is in an early stage of succession and a high density of stems makes sampling 0.04-ha plots impractical.

(2) If 0.004-ha subplots are used, average the results to serve as the value for each 0.04-ha plot.

(3) If multiple 0.04-ha plots are sampled, average the results from all 0.04-ha plots.

(4) Convert the results to a per hectare basis by multiplying by 25. For example, if the average of the 0.04-ha plots is 23 stems, then $23 \times 25 = 575$ stems/ha.

(5) Report the number of understory vegetation stems as stems per hectare.

24. Ground vegetation biomass (V_{GVC})

Measure/Units: Percent cover of ground vegetation.

Methods:

(1) Visually estimate the percentage of the ground surface that is covered by ground vegetation by mentally projecting the leaves and stems of ground vegetation to the ground surface in each of four 1-m^2 sampling units, hereafter called subplots, placed in representative portions of each quadrant of a 0.04-ha plot. The number of 0.04-ha plots required to adequately char-acterize an area will depend on its size and heterogeneity.

(2) Average the values from the four 1-m^2 subplots.

(3) If multiple 0.04-ha plots are sampled, average the results from these plots.

(4) Report ground vegetation cover as a percent.

25. "O" horizon biomass (V_{OHOR})

Measure/Units: Percent cover of the "O" horizon.

Method:

(1) Visually estimate the percent of the ground surface that is covered by an "O" horizon in each of four 1-m^2 subplots placed in representative portions of each quadrant of a 0.04-ha plot. The number of 0.04-ha plots required to adequately characterize the area being assessed will depend on its size and heterogeneity.

(2) Average the results from the subplots.

(3) If multiple 0.04-ha plots were sampled, average the results from these plots.

(4) Report "O" horizon cover as a percent.

26. "A" horizon biomass (V_{AHOR})

Measure/Units: Percent cover of the "A" horizon.

Method: (1) Estimate the percent of the mineral soil within the top 15 cm (6 in.) of the ground surface that qualifies as an "A" horizon by making a number of soil observations in each of four 1-m^2 subplots placed in representative portions of each quadrant of a 0.04-ha plot. For instance, if, in each subplot, 12 soil plugs are taken and 6 show the presence of a 7.5-cm- (3-in.-) thick "A" horizon, the value of "A" horizon cover is $(6 / 12) \times 100 = 50\%$. The number of 0.04-ha plots required to adequately characterize the area being assessed will depend on its size and heterogeneity.

(2) Average the results from the 1-m^2 subplots.

(3) If multiple 0.04-ha plots were sampled, average the results from these plots.

(4) Report "A" horizon cover as a percent.

27. Plant species composition (V_{COMP})

Measure/Units: Percent concurrence with the dominant species in all vegetation strata.

Method: (1) Identify the dominant species in the canopy, understory vegetation, and ground vegetation strata using the 50/20 rule.[1] Use tree basal area to determine abundance in the canopy strata, understory vegetation density to determine abundance in the understory strata, and ground vegetation cover to determine abundance in the ground vegetation strata. To apply the 50/20 Rule, rank species from each strata in descending order of abundance. Identify dominants by summing the normalized abundance measure beginning with the most abundant species in descending order until 50 percent is exceeded. Additional species with ≥20 percent normalized abundance are also considered as dominants. Accurate species identification is critical for determining the dominant species in each plot. Sampling during the dormant season may require a high degree of proficiency in identifying tree bark or dead plant parts. Users who do not feel confident in identifying plant species in all strata should get help with plant identification.

---

[1] OCE Memorandum, 6 March 1992, Clarification of Use of the 1987 Delineation Manual.

(2) For each vegetation strata, calculate percent concurrence by comparing the list of dominant plant species from each strata to the list of dominant species for each strata in reference standard wetlands in Table B7. For example, if all the dominants from the area being assessed occur on the list of dominants from reference standard wetlands, then there is 100 percent concurrence. If 3 of the 5 dominant species of trees from the area being assessed occur on the list, then there is 60 percent concurrence.

Table B7
Dominant Species by Vegetation Strata in Reference Standard Sites in Western Kentucky

Tree	Shrub/Sapling	Ground Vegetation
Acer rubrum	*Acer rubrum*	*Arundinaria gigantea*
Betula nigra	*Betula nigra*	*Aster* sp.
Carya laciniosa	*Carya laciniosa*	*Boehmaria cylindrica*
Celtis laevigata	*Carpinus caroliniana*	*Campsis radicans*
Fraxinus pennsylvanica	*Celtis laevigata*	*Carex squarosa*
Liquidambar styraciflua	*Celtis occidentalis*	*Eragrostis alba*
Quercus pagodifolia	*Fraxinus pennsylvanica*	*Glyceria striata*
Quercus phellos	*Ilex decidua*	*Hypericum* sp.
Quercus lyrata	*Liquidambar styraciflua*	*Impatiens capensis*
Quercus imbricaria	*Nyssa sylvatica*	*Panicum* sp.
Quercus michauxii	*Quercus imbricaria*	*Parthenocissus quinquefolia*
Quercus stellata	*Quercus lyrata*	*Pilea pumila*
Quercus palustris	*Quercus phellos*	*Quercus phellos*
Salix nigra	*Quercus palustris*	*Salix nigra*
	Quercus pagodifolia	*Sauraurus cernuus*
	Quercus stellata	*Smilacina racemosa*
	Platanus occidentalis	*Smilax rotundifolia*
	Salix nigra	*Sparganium* sp.
	Ulmus americana	*Toxicodendron radicans*

(3) Average the percent concurrence from all three strata.

(4) Report percent concurrence with the dominant species in all vegetation strata.

Summary of Variables by Function

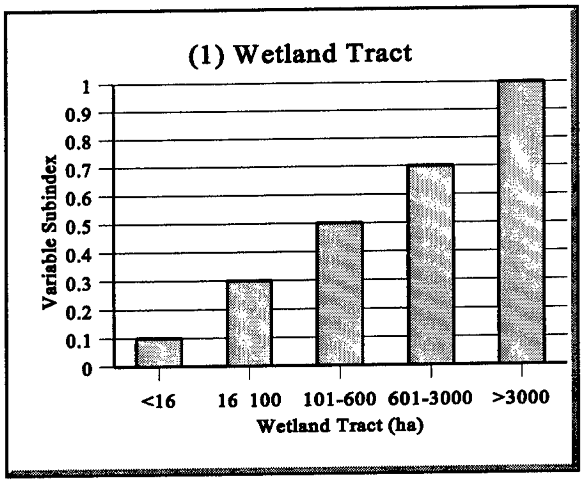
This section provides a listing of the model variables by function.

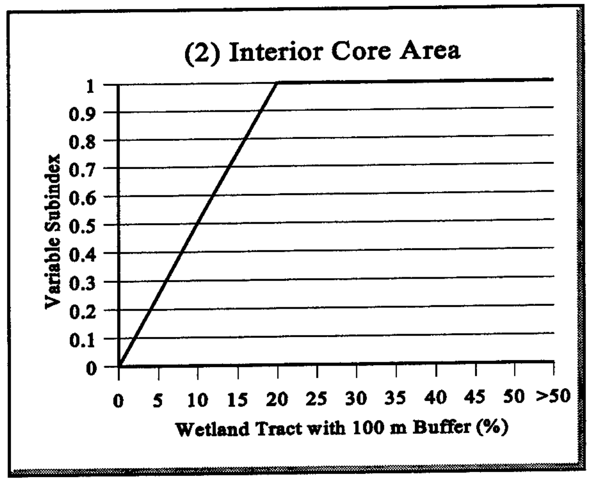
Variables	Function
1. Wetland tract (V_{tract})	Provide habitat for wildlife
2. Interior core area (V_{core})	Provide habitat for wildlife
3. Habitat connections ($V_{connect}$)	Provide habitat for wildlife
4. Floodplain slope (V_{slope})	Temporarily store surface water Retain particulates
5. Floodplain storage volume (V_{store})	Temporarily store surface water Retain particulates
6. Macrotopographic features (V_{macro})	Provide habitat for wildlife
7. Overbank flood frequency (V_{freq})	Temporarily store surface water Remove and sequester elements and compounds Retain particulates Export organic carbon Maintain characteristic plant community Provide habitat for wildlife
8. Floodplain roughness (V_{rough})	Temporarily store surface water Retain particulates
9. Soil integrity ($V_{soilint}$)	Maintain characteristic plant community
10. Water table fluctuation (V_{wtf})	Maintain characteristic subsurface hydrology
11. Water table depth (V_{wtd})	Remove and sequester elements and compounds Maintain characteristic plant community
12. Water table slope ($V_{wtslope}$)	Maintain characteristic subsurface hydrology
13. Subsurface water velocity ($V_{soilperm}$)	Maintain characteristic subsurface hydrology
14. Subsurface storage volume (V_{pore})	Maintain characteristic subsurface hydrology
15. Surface water connections ($V_{surfcon}$)	Export organic carbon
16. Soil clay content (V_{clay})	Remove and sequester elements and compounds
17. Redoximorphic features (V_{redox})	Remove and sequester elements and compounds
	(Continued)

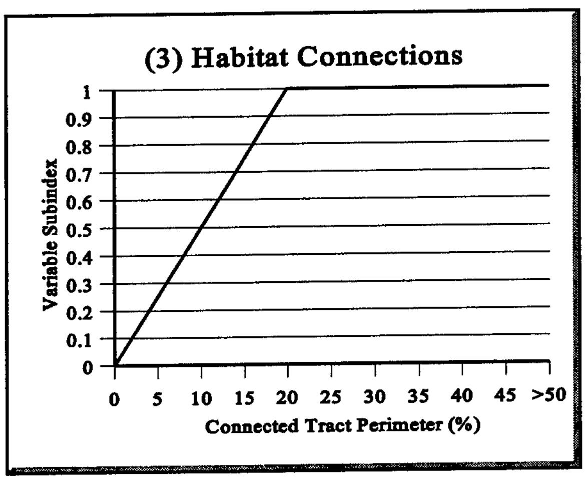
Variables	Function
18. Tree biomass (V_{tba})	Cycle nutrients Maintain characteristic plant community Provide habitat for wildlife
19. Tree density (V_{tden})	Maintain characteristic plant community Provide habitat for wildlife
20. Snag density (V_{snag})	Provide habitat for wildlife
21. Woody debris biomass (V_{wd})	Cycle nutrients Export organic carbon
22. Log biomass (V_{log})	Provide habitat for wildlife
23. Understory vegetation biomass (V_{ssd})	Cycle nutrients
24. Ground vegetation biomass (V_{gvc})	Cycle nutrients
25. "O"horizon biomass (V_{ohor})	Cycle nutrients Remove and sequester elements and compounds Export organic carbon Provide habitat for wildlife
26. "A" horizon biomass (V_{ahor})	Cycle nutrients Remove and sequester elements and compounds
27. Plant species composition (V_{comp})	Maintain characteristic plant community Provide habitat for wildlife

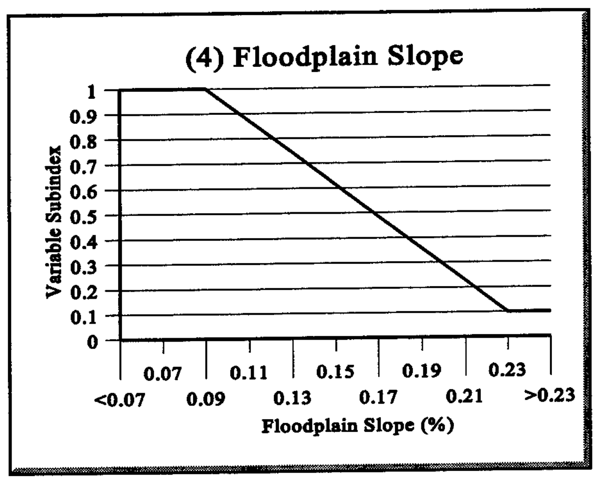
Summary of Graphs for Transforming Measures to Subindices

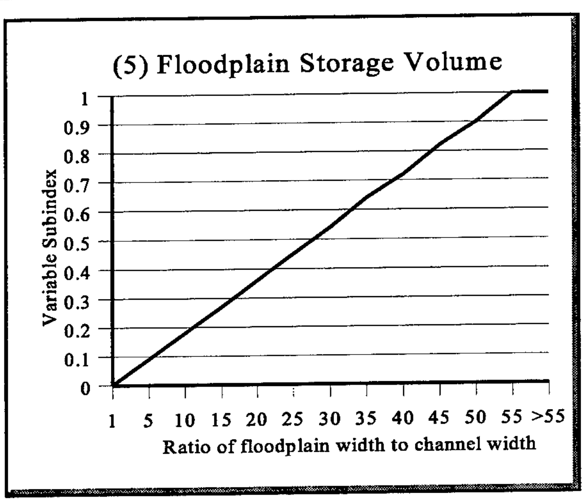
This section provides a summary of the graphical transformation of variable measures to variable subindices.

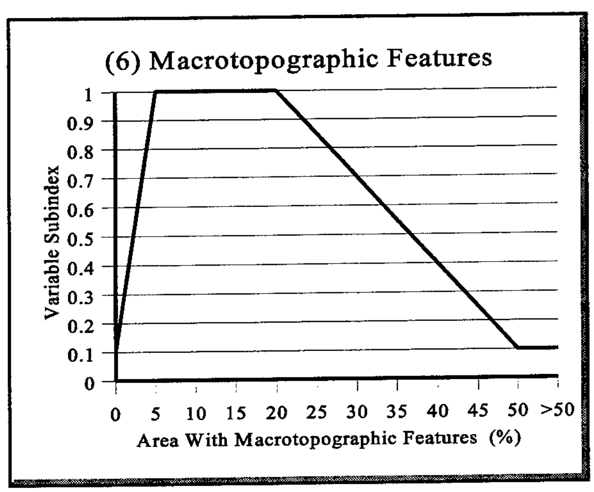


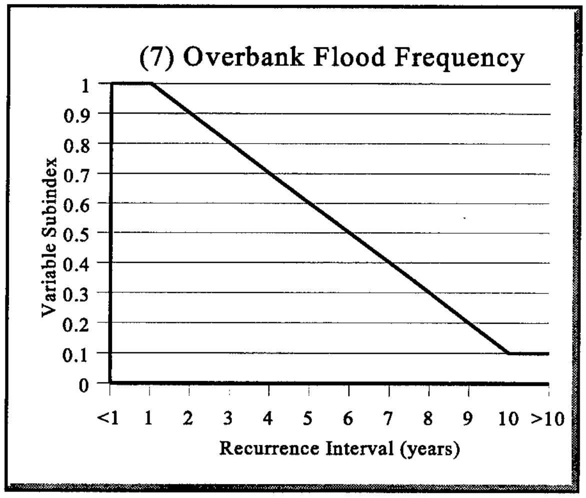




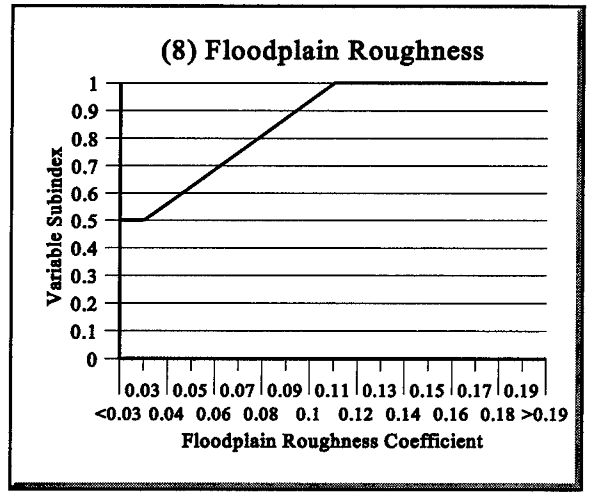




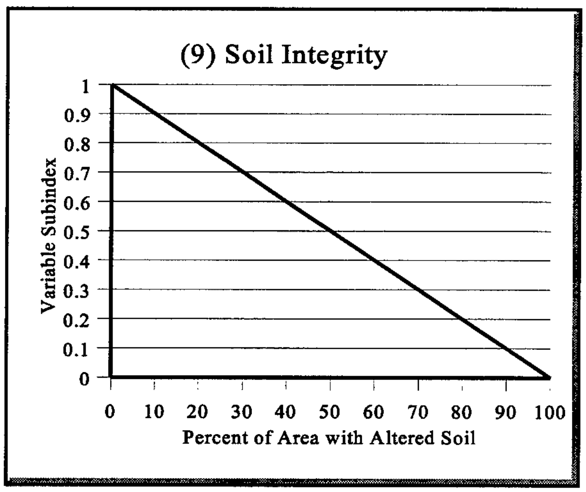




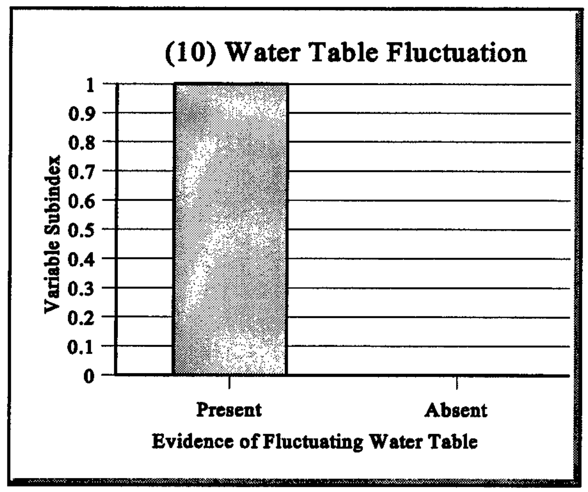
(7) Overbank Flood Frequency
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
<1 1 2 3 4 5 6 7 8 9 10 >10
Recurrence Interval (years)



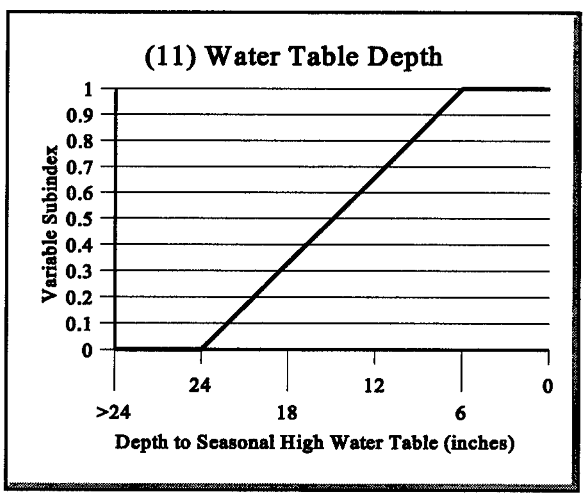
(8) Floodplain Roughness
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.03 0.05 0.07 0.09 0.11 0.13 0.15 0.17 0.19
<0.03 0.04 0.06 0.08 0.1 0.12 0.14 0.16 0.18 >0.19
Floodplain Roughness Coefficient



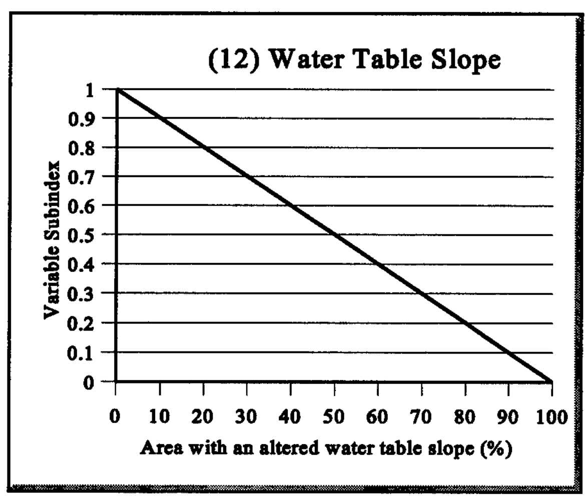
(9) Soil Integrity
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 10 20 30 40 50 60 70 80 90 100
Percent of Area with Altered Soil



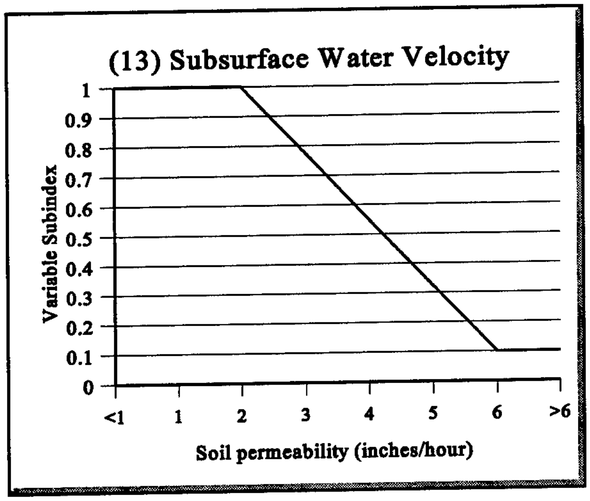
(10) Water Table Fluctuation
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Present
Absent
Evidence of Fluctuating Water Table

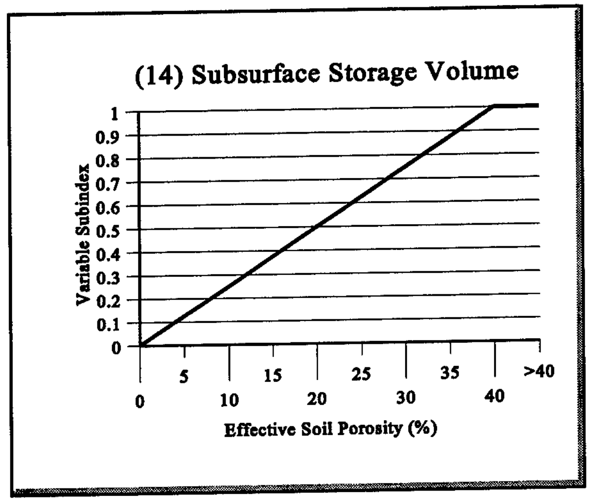


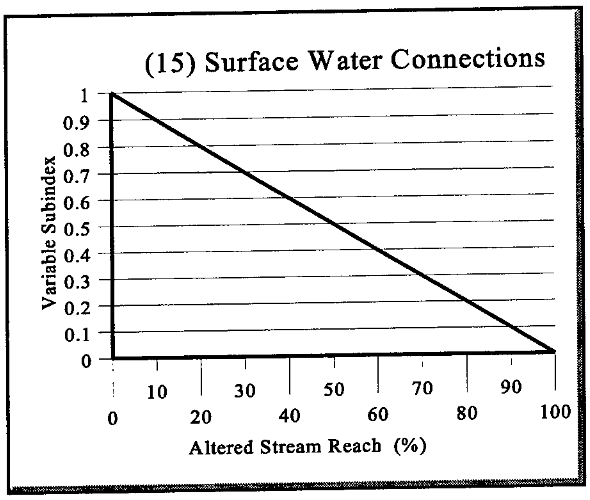
(11) Water Table Depth
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
24 12 0
>24 18 6
Depth to Seasonal High Water Table (inches)

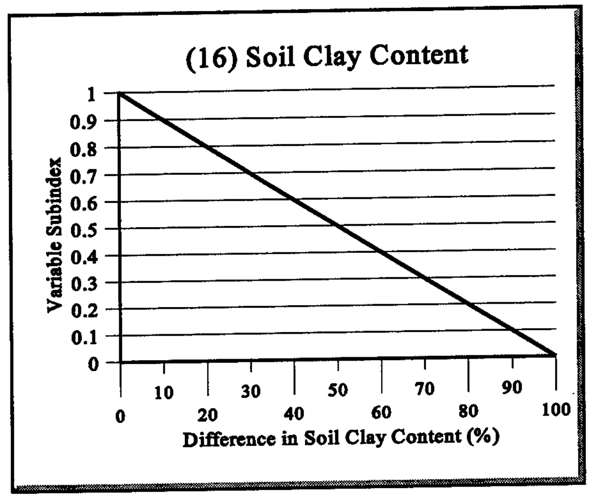


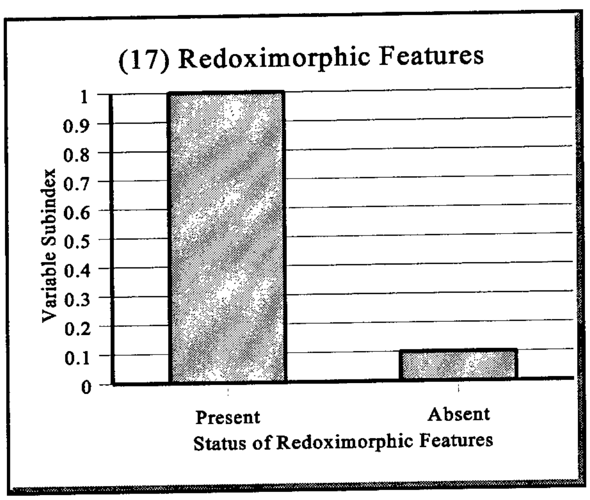
(12) Water Table Slope
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 10 20 30 40 50 60 70 80 90 100
Area with an altered water table slope (%)

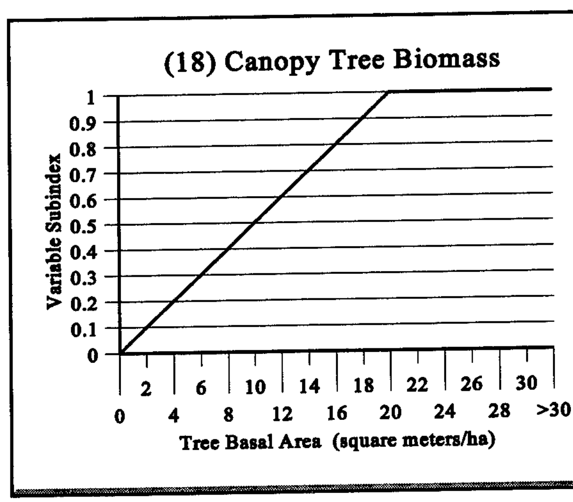

(13) Subsurface Water Velocity
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
<1
1
2
3
4
5
6
>6
Soil permeability (inches/hour)

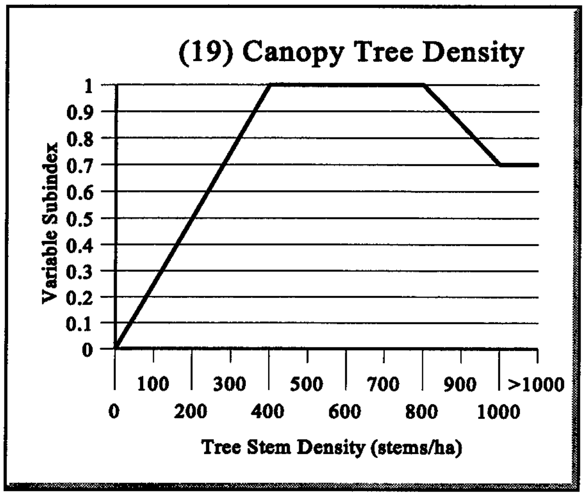

(14) Subsurface Storage Volume
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
5
10
15
20
25
30
35
40
>40
Effective Soil Porosity (%)

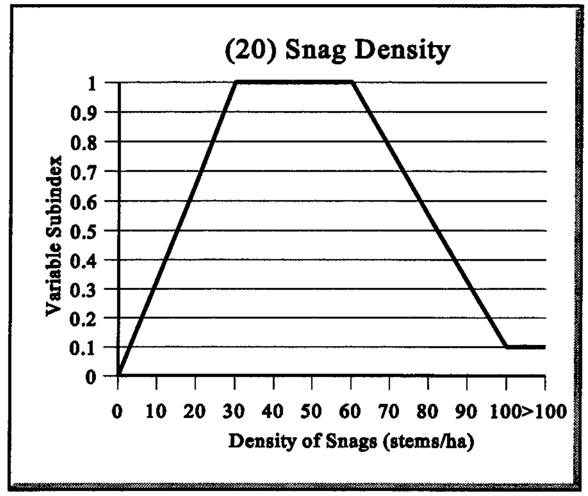

(15) Surface Water Connections
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
60
70
80
90
100
Altered Stream Reach (%)

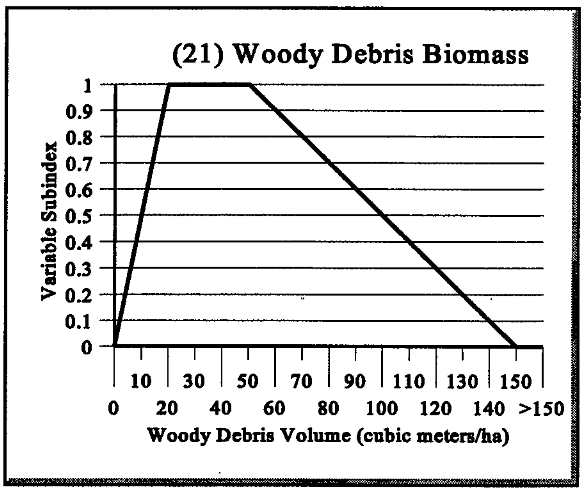

(16) Soil Clay Content
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
60
70
80
90
100
Difference in Soil Clay Content (%)

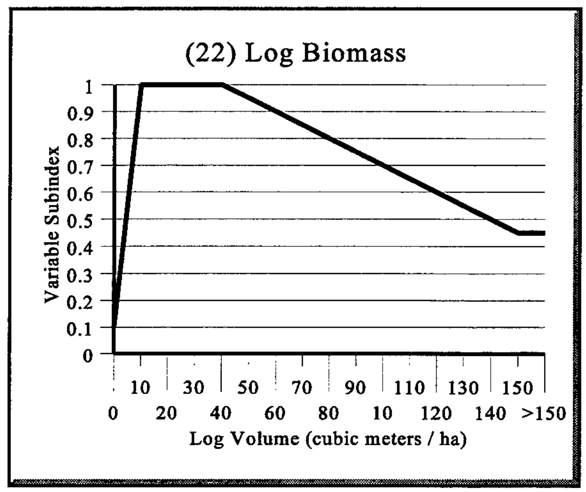

(17) Redoximorphic Features
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Present
Absent
Status of Redoximorphic Features

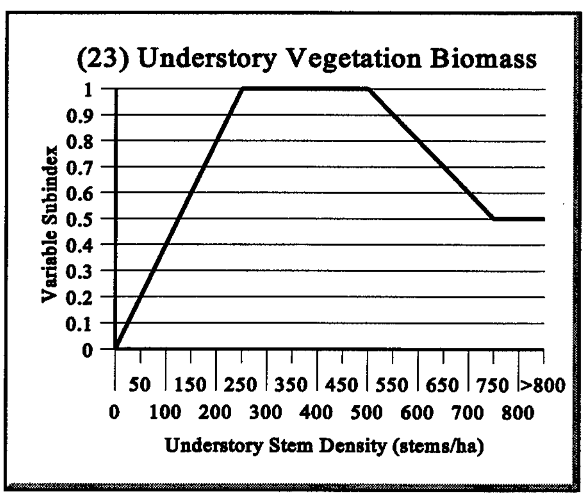

(18) Canopy Tree Biomass
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
>30
Tree Basal Area (square meters/ha)

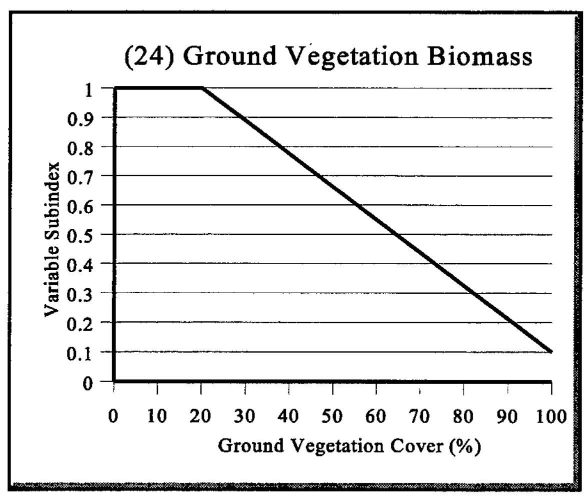

(19) Canopy Tree Density
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
100 300 500 700 900 >1000
0 200 400 600 800 1000
Tree Stem Density (stems/ha)

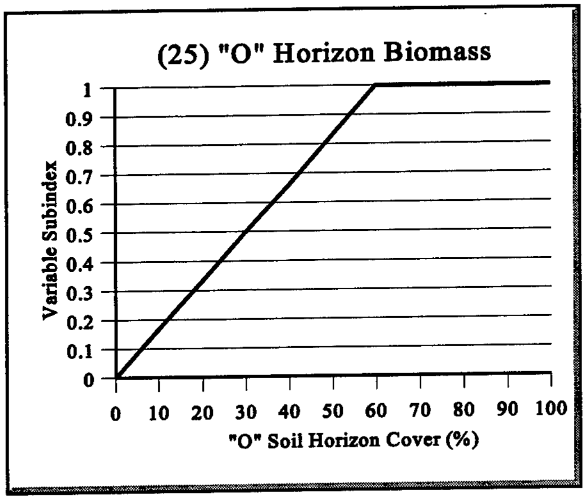

(20) Snag Density
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 10 20 30 40 50 60 70 80 90 100>100
Density of Snags (stems/ha)

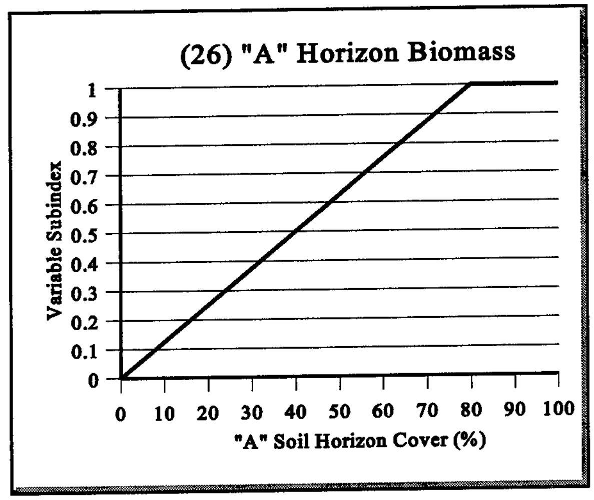

(21) Woody Debris Biomass
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
10 30 50 70 90 110 130 150
0 20 40 60 80 100 120 140 >150
Woody Debris Volume (cubic meters/ha)

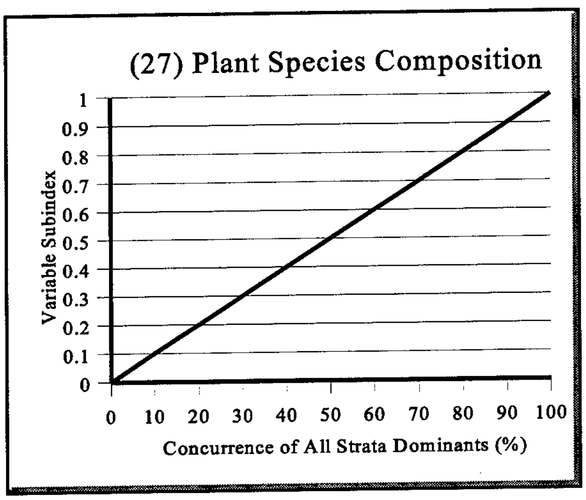

(22) Log Biomass
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
10 30 50 70 90 110 130 150
0 20 40 60 80 10 120 140 >150
Log Volume (cubic meters / ha)


(23) Understory Vegetation Biomass
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
50 150 250 350 450 550 650 750 >800
0 100 200 300 400 500 600 700 800
Understory Stem Density (stems/ha)


(24) Ground Vegetation Biomass
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 10 20 30 40 50 60 70 80 90 100
Ground Vegetation Cover (%)


(25) "O" Horizon Biomass
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 10 20 30 40 50 60 70 80 90 100
"O" Soil Horizon Cover (%)


(26) "A" Horizon Biomass
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 10 20 30 40 50 60 70 80 90 100
"A" Soil Horizon Cover (%)


(27) Plant Species Composition
Variable Subindex
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 10 20 30 40 50 60 70 80 90 100
Concurrence of All Strata Dominants (%)

Field Data Sheet: Low Gradient Riverine Wetlands in Western Kentucky

Assessment Team : ____
Project Name/Location: ______________________________ **Date :**__________

Sample variables 1-6 using aerial photos, topographic maps, scenic overlooks, local informants, etc.

1. V_{TRACT} Area of wetland that is contiguous with the WAA *and* of the same subclass . . . . . . _____ ha

2. V_{CORE} Percent of wetland tract that is >300 m from unsuitable habitat . . . . _____ %

3. $V_{CONNECT}$ Percent of wetland tract perimeter that is "connected" to suitable habitat . . _____ %

4. V_{SLOPE} Percent floodplain slope . . . . _____ %

5. V_{STORE} Floodplain width to channel width ratio . . . . _____

6. V_{MACRO} Percent of WAA covered with macrotopographic features . . . . _____ %

Sample variables 7-17 based on a walking reconnaissance of the WAA

7. V_{FREQ} Overbank flood recurrence interval . . . . _____ years
Check data source: gage data __, local knowledge __, flood frequency curves __, regional dimensionless curve __, hydrologic modeling __, other ____________ .

8. V_{ROUGH} Roughness Coefficient ___ (n_{BASE}) + ___ (n_{TOPO}) + ___ (n_{OBS}) + ___ (n_{VEG}) = ... _____

9. $V_{SOILINT}$ Percent of WAA with altered soils . . . . _____ %.

10. V_{WTF} Water table fluctuation is (check one): . . . . present _____ absent _____
Check data source: groundwater well, __ redoximorphic features, __ County Soil Survey __.

11. V_{WTD} Water table depth is . . . . _____ inches
Check data source: groundwater well, __ redoximorphic features, __ County Soil Survey __.

12. $V_{WTSLOPE}$ Percent of WAA with an altered water table slope . . . . _____ %

13. $V_{SOILPERM}$ Soil permeability . . . . _____ (in./hr)

14. V_{PORE} Percent effective soil porosity . . . . _____ %

15. $V_{SURFCON}$ Percent of adjacent stream reach with altered surface connections . . . . _____ %

16. V_{CLAY} Percent of WAA with altered clay content in soil profile . . . . _____ %

17. V_{REDOX} Redoximorphic features are (check one): . . . . present _____ absent _____

Sample variables 18-20 from a representative number of locations in the WAA using a 0.04 ha circular plot (11.3 m (37 ft) radius)

18. V_{TBA} Tree basal area (average of 0.04 ha plot values on next line) . . . . ____ m^2/ha
0.04 ha plots: 1 ____ m^2/ha 2 ____ m^2/ha 3 ____ m^2/ha 4 ____ m^2/ha

19. V_{TDEN} Number of tree stems (average of 0.04 ha plot values on next line) . . . . ____ stems / ha
0.04 ha plots: 1 ____ stems/ha 2 ____ stems/ha 3 ____ stems/ha 4 ____ stems/ha

20. V_{SNAG} Number of snags (average of 0.04 ha plot values on next line) . . . . ____ stems / ha
0.04 ha plots: 1 ____ stems/ha 2 ____ stems/ha 3 ____ stems/ha 4 ____ stems/ha

Sample variables 21-22 on two (2) 15 m transects partially within the 0.04 ha plot

21. V_{WD} Volume of woody debris (average of transect values on next line) . . . . ____ m^3/ha
Transect: 1 ____ m^3/ha 2 ____ m^3/ha 3 ____ m^3/ha 4 ____ m^3/ha

22. V_{LOG} Volume of logs (average of transect values on next line) . . . . ____ m^3/ha
Transect: 1 ____ m^3/ha 2 ____ m^3/ha 3 ____ m^3/ha 4 ____ m^3/ha

Sample variable 23 in two (2) 0.004 ha circular subplots (3.6 m (11.8 ft) radius) placed in representative locations of the 0.04 ha plot

23. V_{SSD} Number of woody understory stems (average of 0.04 ha plot values on next line)
. . . . ____ stems / ha
0.04 ha plots: 1 ____ stems/ha 2 ____ stem/ha 3 ____ stems/ha 4 ____ stems/ha

Sample variables 24-26 in four (4) m^2 subplots placed in representative locations of each quadrant of the 0.04 ha plot

24. V_{GVC} Average cover of ground vegetation (average of 0.04 ha plot values on next line) . . ____ %
Average of 0.04 ha plots sampled: 1 ____ % 2 ____ % 3 ____ % 4 ____ %

25. V_{OHOR} Average cover of "O" Horizon (average of 0.04 ha plot values on next line) . . . . . . ____ %
Average of 0.04 ha plots sampled: 1 ____ % 2 ____ % 3 ____ % 4 ____ %

26. V_{AHOR} Average cover of "A" Horizon (average of 0.04 ha plot values on next line) . . . . . . ____ %
Average of 0.04 ha plots sampled: 1 ____ % 2 ____ % 3 ____ % 4 ____ %

27. V_{COMP} Concurrence with all strata dominants (average of 0.04 ha plot values on next line) ____ %
Average of 0.04 ha plots sampled: 1 ____ % 2 ____ % 3 ____ % 4 ____ %

Plot Worksheet: Low Gradient Riverine Wetlands in Western Kentucky

Assessment Team : ____

Project Name/Location : ____________________ **Plot Number :** _____ **Date :** ________

Record dbh (cm) of trees by species below, square dbh values (cm^2), multiply result by 0.000079 (m^2), and sum resulting values in shaded columns (m^2/0.04 ha). Record in 18. V_{TBA}, multiply by 25 (m^2/ha).

Species	dbh (cm)	dbh^2 (cm^2)	× 0.00079 (m^2/0.04 ha)	Species	dbh (cm)	dbh^2 (cm^2)	× 0.00079 (m^2/0.04 ha)

18. V_{TBA} Sum of values from shaded columns above = ______ (m^2/0.04 ha) × 25 = _________ m^2/ha

19. V_{TDEN} Total number of tree stems from above = _______ (stems/0.04 ha) × 25 = ________ stems/ha

20. V_{SNAG} Total number of snag stems from above= _____ (stems/0.04 ha) × 25 = _________ stems/ha

21/22. V_{WD} / V_{LOG}

Record number of stems in Size Class 1 (0.6-2.5 cm / 0.25-1 in) along a 6 ft section of Transect 1 and 2

Transect 1 _______ Transect 2 _______ *Total number of stems* = _______

Size Class 1 tons /acre = 0.187 × *total number of stems* = ... _____ tons/acre

Record number of stems in Size Class 2 (2.5 - 7.6 cm / 1-3 in) along 12 ft section of Transect 1 and 2

Transect 1_______ Transect 2 _______ *Total number of stems* = _______

Size Class 2 tons / acre = 0.892 × *total number of stems* = ... _____ tons/acre

Record diameter of stems in Size Class 3 (> 7.6 cm / >3 in) along 50 ft section of Transect 1 and 2

<u>Transect 1</u>	diameter	diameter^2	<u>Transect 2</u>	diameter	diameter^2
Stem 1 =	_____	_____	Stem 1 =	_____	_____
Stem 2 =	_____	_____	Stem 2 =	_____	_____
Stem 3 =	_____	_____	Stem 3 =	_____	_____
Stem 4 =	_____	_____	Stem 4 =	_____	_____
Total diameter^2		_____	Total diameter ^{2}		_____

Total diameter^2 of stems from both transects = _____

Size Class 3 tons / acre = 0.0687 × *Total diameter* ^{2} *of stems from both transects* = . _____ tons/acre
Total tons / acre (sum of Size Classes 1-3 from above) = ... _____ tons/acre
Cubic feet / acre = (32.05 × *total tons / acre*) / 0.58 = ... _____cubic feet/acre
Cubic meters / ha = *cubic feet / acre* × 0.069 . . . . _____ cubic meters/ha

23. V_{SSD} Tally woody understory stems two 0.004 ha subplots then average and multiply by 250:
Subplot 1 __________ Subplot 2 __________ Average ____ × 250 = . _____ stems/ha

24. V_{GVC} Estimate percent cover of ground vegetation in four m^2 subplots then average:
1 ____ % 2 ____ % 3 ____ % 4 ____ % . . . . Average _____ %

25. V_{OHOR} Estimate percent cover of "O" Horizon in four m^2 subplots then average:
1 ____ % 2 ____ % 3 ____ % 4 ____ % . . . . Average _____ %

26. V_{AHOR} Estimate percent cover of "A" Horizon in four m^2 subplots then average:
1 ____ % 2 ____ % 3 ____ % 4 ____ % . . . . Average _____ %

27. V_{COMP} Determine percent concurrence with each strata using the table below
Tree = ___ % Shrub/Sapling = ___ % Ground Vegetation = ___ % . . . . Average _____ %

Dominant Species by Strata in Western Kentucky Low Gradient Riverine Wetlands		
Tree	Shrub/Sapling	Ground Vegetation
Acer rubrum	*Acer rubrum*	*Arundinaria gigantea*
Betula nigra	*Betula nigra*	*Aster* sp.
Carya laciniosa	*Carya laciniosa*	*Boehmaria cylindrica*
Celtis laevigata	*Carpinus caroliniana*	*Campsis radicans*
Fraxinus pennsylvanica	*Celtis laevigata*	*Carex squarosa*
Liquidambar styraciflua	*Celtis occidentalis*	*Eragrostis alba*
Quercus pagodifolia	*Fraxinus pennsylvanica*	*Glyceria striata*
Quercus phellos	*Ilex decidua*	*Hypericum* sp.
Quercus lyrata	*Liquidambar styraciflua*	*Impatiens capensis*
Quercus imbricaria	*Nyssa sylvatica*	*Panicum* sp.
Quercus michauxii	*Quercus imbricaria*	*Parthenocissus quinquefolia*
Quercus stellata	*Quercus lyrata*	*Pilea pumila*
Quercus palustris	*Quercus phellos*	*Quercus phellos*
Salix nigra	*Quercus palustris*	*Salix nigra*
	Quercus pagodifolia	*Sauraurus cernuus*
	Quercus stellata	*Smilacina racemosa*
	Platanus occidentalis	*Smilax rotundifolia*
	Salix nigra	*Sparganium* sp.
	Ulmus americana	*Toxicodendron radicans*

Appendix C
Supplementary Information on Model Variables

This appendix contains the following summaries:

Ellipse Equation

The equation was originally developed to approximate the spacing and depth of ditches for agriculture. It is currently being used to determine hydrologic alteration in the context of crop production where the usual requirement is to lower the water table below the root zone within 24 to 48 hr after saturation (USDA NRCS 1996).[1] The objective of utilizing the ellipse equation in this Regional Guidebook is to assess the extent that a drainage ditch affects the wetland assessment area (WAA). The water table slope in the WAA is assumed to mimic the surface of the wetland surface except when ditches, wells, or other alterations cause it to be modified. If a ditch is present or the stream channel has been deepened, then the lateral extent of the effect on water table slope must be determined. The ellipse equation is used as an indicator of alteration to the water table slope by providing an approximation of the lateral effect of a ditch. The following is a summary of Chapter 19, Part 650.1905 of the NRCS Engineering Field Handbook, entitled "Hydrology Tools for Wetland Determination" (USDA NRCS 1996).

The data required to use the ellipse equation include:

a. weighted average of the saturated hydraulic conductivity (K) above the restrictive layer

b. parallel drain or ditch spacing

c. depth of barrier or impervious layer

d. drainage rate

e. depth to drain

f. vertical distance, after drawdown, of water table above the drain and at midpoint between the drains

The accuracy of results of the ellipse equation are affected by:

a. significant surface inflow

b. rainfall during the evaluation period

c. spacing and impact of drains, which may be approximate because infiltration was not considered

d. evapotranspiration, which was not considered in developing this model

The equation is:

[1] References cited in this appendix are listed in the References at the end of the main text.

$$S = \sqrt{(4K)\,\frac{(m^2 + 2am)}{q}} \qquad \text{(C1)}$$

where

S = parallel drain spacing (ft) (Figure C1)

K = weighted average of the hydraulic conductivity above the restrictive layer (in./hr)

m = vertical distance (d-c), after drawdown, of water table above drain and at midpoint between drains (ft)

d = depth to drain from the surface (ft)

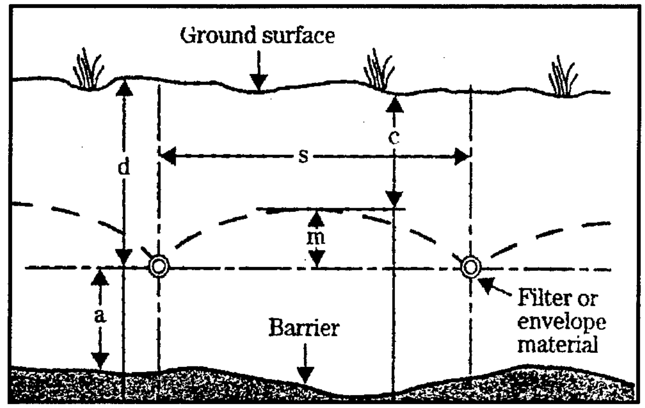


Figure C1. Parallel drain spacing (USDA NRCS 1996)

c = depth to water table drawdown after the evaluation period (ft)

a = depth of barrier (impermeable layer) below drains (ft)

q = drainage rate (in./hr)

The drainage rate (q) is calculated using:

$$q = \frac{v}{t} \qquad \text{(C2)}$$

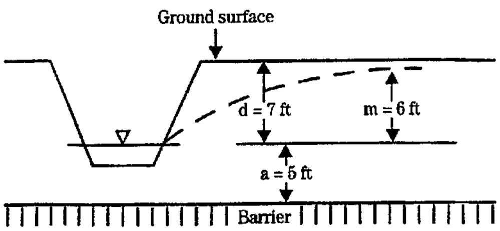
where

v = volume of water that will drain from a known volume of water through the forces of gravity

t = duration of saturation

The weighted average of the saturated hydraulic conductivity (K) is calculated using:

$$K = \frac{KaDa + KbDb + KxDx}{Da + Db + Dx} \qquad \text{(C3)}$$



Step 1 $m = d - c = 7 - 1 = 6 \text{ ft}$

Step 2 $K = 1.14 \text{ in/hr } (24 \text{ hr/d}) = 27.36 \text{ in/d}$

Step 3 v = (F)(c) or v may be obtained from the soil properties

$q = (0.05 \text{ ft/ft})(1 \text{ ft}) = 0.05 \text{ ft}$

Converted to inches:

$q = (0.05 \text{ ft})(12 \text{ in/ft/ft}) = 0.6 \text{ inch}$

Step 4 $q = \frac{v}{t} = \frac{0.6 \text{ in}}{14 \text{ d}} = 0.043 \text{ in/d}$

Step 5 $S = \sqrt{(4K)\frac{(m^2 + 2am)}{q}}$

Step 6 $S = \sqrt{4(27.36 \text{ in/d})\frac{\left[(6)^2 + 2(5 \text{ ft})(6 \text{ ft})\right]}{0.043 \text{ in/d}}}$

$S = 494 \text{ ft}$

Figure C2. Steps for determining the lateral effects of a ditch

where

Ka = saturated hydraulic conductivity of soil layer *a*

Da = depth of soil layer *a*

Kb = saturated hydraulic conductivity of soil layer *b*

Db = depth of soil layer *b*

Figure C2 provides an example of the steps used in determining the lateral effects of a ditch.

Effective Soil Porosity

The effective porosity is the amount of pore space available for storage after adjusting for antecedent moisture conditions. Not accounting for antecedent moisture conditions or the heterogeneity of the site, the effective porosity is assumed to be equivalent to available capacity for retention of groundwater. This variable is esti-mated using the following relationship described by Pruitt and Nutter (unpublished manuscript):

Effective porosity = total porosity - residual water content

where

Effective porosity = the ratio of pore space through which water moves to the total volume of pore space available in a soil

Total porosity = the percentage of soil volume occupied by pores

Residual water content = the amount of water held by osmotic and capillary forces which does not freely drain from the soil and represents antecedent moisture content

Total porosity is calculated using the following relationship:

$$\text{Total porosity} = 100 \times (1 - p_d / p_b)$$

where

p_d = median soil bulk density for a given soil series (g/cm^3)

p_b = particle density, g/cm^3 (assumed to be 2.65 g/cm^3)

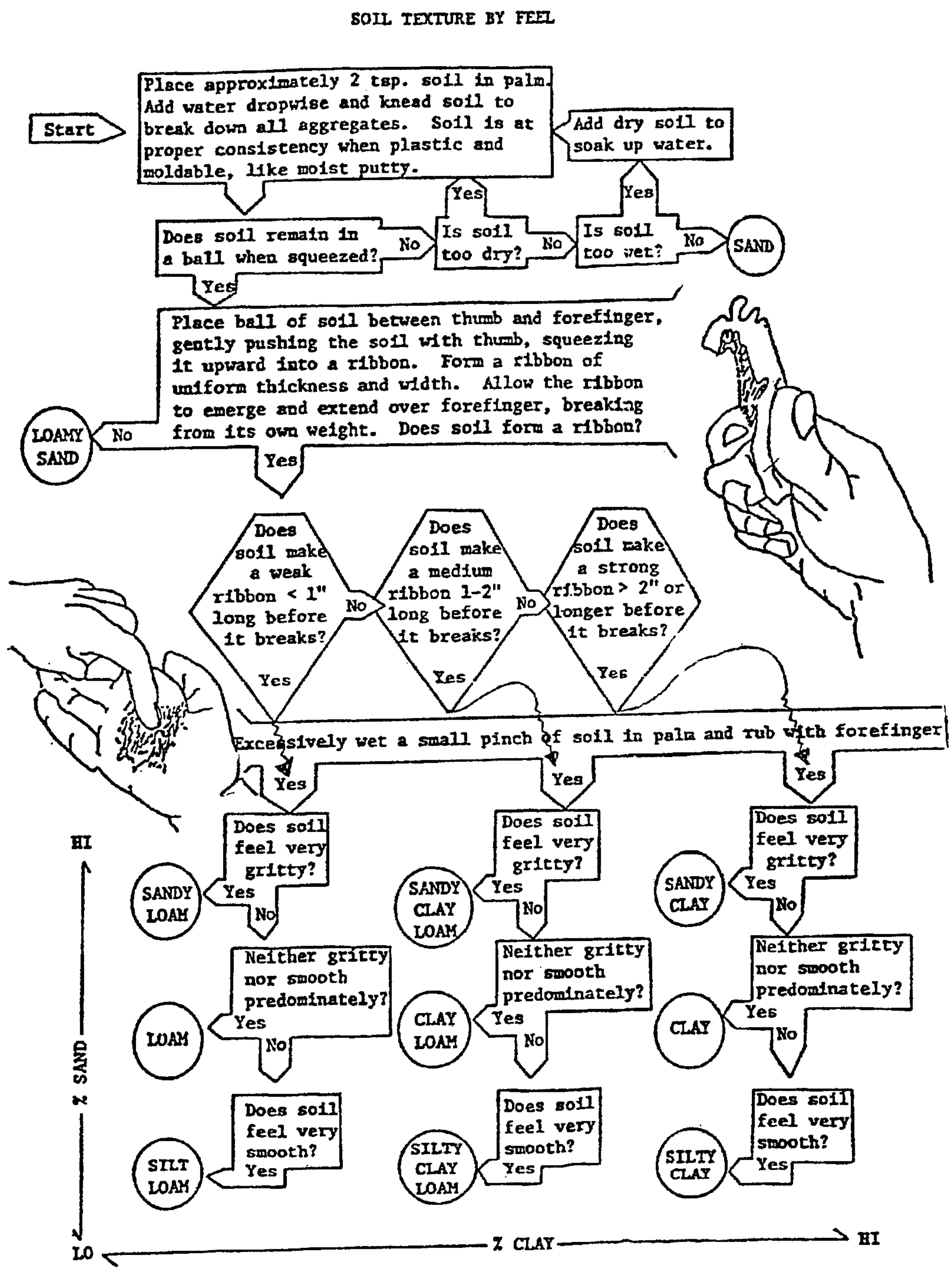
Information on median bulk soil density (p_d) is available from bulk density ranges reported in the Physical Properties Table of County Soil Surveys or SCS Soil Interpretation Record. Particle density (p_b) is assumed to be 2.65 g/cm^3 (Fetter 1980). The information on residual water content in Table C1 is from Rawls et al. (1993).

Table C1
Residual Water Content by Soil Texture Class

Soil Texture Class	Residual Water Content, percent
Sand	2.0
Loamy sand	3.5
Sandy loam	4.1
Loam	2.7
Silt loam	1.5
Sandy clay loam	6.8
Clay loam	7.5
Silty clay loam	4.0
Sandy clay	10.9
Silty clay	5.6
Clay	9.0

Soil Texture by Feel

Clay content in soils can be measured in a laboratory by conducting a particle size analysis. However, this is often impracticable in a rapid assessment scenario. Clay content can be estimated in the field using the soil-texture-by-feel method to determine the texture class (Figure C3), and the soil texture triangle to estimate percent clay (Figure C4).



Adapted from: Thien, Steve J. 1979. A flow diagram for teaching texture-by-feel analysis. Journal of Agronomic Education, 8:54-55.

Figure C3. Estimating soil texture by "feel"

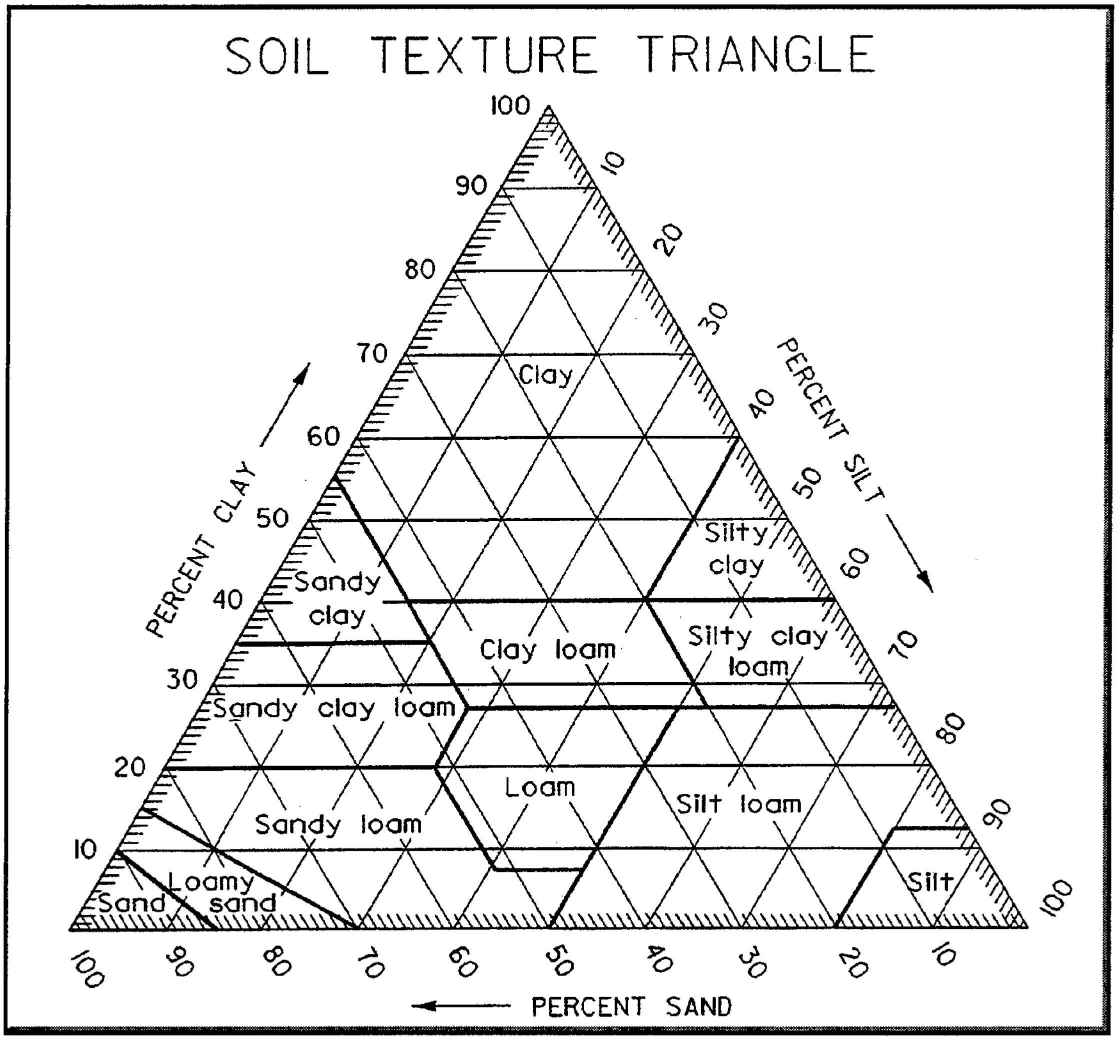


Figure C4. Soil texture triangle

Pumping Test

Soil hydraulic conductivity (soil permeability) can be directly measured using the pumping test (also referred to as a "slug" test). Freeze and Cherry (1979) describe the pumping test as a method to determine the hydraulic conductivity of a soil. In essence, this test involves a rapid removal of a known volume of water from a piezometer, causing an instantaneous change in the water level. This rapid withdrawl is sometimes accomplished by bailing the water out of the well or by using compressed air to push the water out of the well (Dawson and Istok 1991). The recovery of the water level in the well is then observed. The rate of inflow of water back into the well is then proportional to the hydraulic conductivity. The method of interpreting the water level versus time relationship that arises from these tests depends on which of two "test configurations" is considered most representative. For a more complete discussion, the end user is referred to Freeze and Cherry (1979) or Dawson and Istok (1991).

Flood Frequency Analysis Methods

The objective of determining the frequency of flooding at a particular site is to ascertain how often flood waters reach the wetland surface. This is a critical consideration in assessing the functional capacity of riverine wetlands and can be accomplished in a number of ways. However, each method has shortcomings which must be considered before utilizing a particular technique.

Streamflow frequency analysis

Gage data from stream gages in the area can be used to develop a flood frequency curve which establishes the flood frequency-magnitude relationship. This requires obtaining the historical record of peak flows (annual maximum series) or the historical record of flows above an arbitrary flow (partial duration series) from a gage or series of gages in the vicinity of the wetland assessment area. These data can be obtained from the United States Geological Survey (USGS) Internet site www.usgs.gov ; USGS Water Resources Reports; or commercial databases (e.g., EarthInfo, Inc.) which essentially "package" USGS data in a user-friendly manner. If a particular gaging station has a long period of record (i.e., >20 years) then the annual maximum series can be used for the flood frequency analysis. However, if the period of record is small (i.e., <20 years) then a partial duration series should be used.

Once the data are obtained, the discharges are ranked from highest discharge to lowest discharge. The flood recurrence interval can be calculated from this ranked data using the Weibull Method (Ritter, Kochel, and Miller 1995) which calculates the recurrence interval by taking the average time between two floods of equal or greater magnitude:

$$R = \frac{n + 1}{m} \tag{C4}$$

where

R = recurrence interval in years

n = number of discharge values (i.e., number of years of record in the annual series)

m = magnitude rank of a given flood

The results of this analysis are plotted on probability graph paper or by using a computer spreadsheet to show the relationship of discharge to recurrence interval. The curve can be used to estimate the magnitude of a flood that can be expected within a specified period of time.

USGS and other Federal agencies use the Log Pearson Type III (U.S. Water Resources Council 1981) technique which utilizes a log transformation of the data and utilizes the mean, standard deviation, and skewness of the annual flood series. The Log Pearson Type III method, like the Weibull Method, utilizes actual gage data to calculate the recurrence interval for a given discharge and/or the probability at which a given flood discharge is expected to occur in any given year. A more complete discussion and description of these methods can be found in Dunne and Leopold (1978).

However, neither the Weibull Method nor the Log Pearson Type III analysis can be used to estimate whether a given flood with a given recurrence interval will actually overtop the streambanks and reach the wetland surface. For instance, in the Piedmont of Georgia, stream channels are incised to such a degree that areas which used to be wetland dominated by overbank flows no longer flood. Therefore, 2- and perhaps even 5-year recurrence interval flood flows do not leave the channel (Burke 1996). Determination of flood heights at the assessment site can only be done when the wetland assessment area is in the proximity of a gage such that gage heights of particular flood events, which are correlated to actual elevations (NGVD), can be directly compared with elevations on the wetland site. Correlation of gage heights with wetland surface elevations requires surveying expertise and becomes more complex the further the wetland sites are from the gage. Further, wetland assessment areas are often in ungaged watersheds and gage data are not available.

Regional flood frequency curves

The Weibull and Log Pearson Type III flood frequency analysis techniques involve the use of actual gage data to determine flood frequency. Often this data in a particular watershed or the ability to obtain and process this data is unavailable. In these situations, the USGS has developed regional regression equations for estimating flood frequency and magnitude at ungaged sites in many regions of the United States. These regionalization procedures relate flood characteristics to watershed and climatic characteristics through the use of correlation or regression techniques. These regression equations are used to transfer flood characteristics from gaged to ungaged sites through the use of watershed and climatic characteristics as explanatory or predictor variables (Jennings, Thomas, and Riggs 1994). In other words, flood characteristics can be estimated for ungaged sites by determining the needed watershed and climatic character-istics for the gaged site and correlating these characteristics to the ungaged site. The regression equations for Kentucky are described and explained in Choquette (1988) and Jennings, Thomas, and Riggs (1994).

According to Jennings, Thomas, and Riggs (1994) and Choquette (1988) Kentucky is divided into seven hydrologic regions (Figure C9). The western Kentucky Coalfield occurs in hydrologic regions 6 and 7. The equations in Table C2 can be used to estimate the discharges associated with 2, 5, 10, 25, 50, and 100 year recurrence intervals.

The discharge for the 2-year recurrence interval (*Q*2) can be calculated as can the discharge for the 5-year recurrence interval event (*Q*5) or any other. However, as with the previous techniques for estimating flood frequency, no estimate of flood depth is incorporated in the equation. Therefore, the above equations yield estimates of flood flows but no indication of whether the flow actually overtops the banks.

Hydrologic Engineering Center (HEC) - 1

The HEC-1 computer program is based on mathematical relationships which are intended to represent individual meteorologic, hydrologic, and hydraulic processes that comprise the precipitation-runoff process (Claborn and Dodson 1992). These processes are separated into precipitation, interception/ infiltration, stormflow, and flood hydrograph routing. The model is designed to simulate surface runoff in a particular basin or watershed by representing the basin as

Table C2
Regression Equations for Peak Discharges of Varying Recurrence Intervals for Hydrologic Regions 6 and 7 in the Western Kentucky Coalfield

Peak Discharges at Different Recurrence Intervals	Region 6	Region 7
Q2	$55.0Ac^{0.821}Sc^{0.368}$	$642Ac^{0.659}Bs^{-0.569}Sc^{-0.964}$
Q5	$66.0Ac^{0.839}Sc^{0.422}$	$946Ac^{0.647}Bs^{-0.523}Sc^{-0.809}$
Q10	$71.1Ac^{0.850}Sc^{0.454}$	$1154Ac^{0.642}Bs^{-0.501}Sc^{-0.725}$
Q25	$75.5Ac^{0.865}Sc^{0.494}$	$1424Ac^{0.640}Bs^{-0.482}Sc^{-0.635}$
Q50	$78.8Ac^{0.873}Sc^{0.520}$	$1636Ac^{0.639}Bs^{-0.472}Sc^{-0.579}$
Q100	$81.3Ac^{0.882}\ Sc^{0.545}$	$1838Ac^{0.639}Bs^{-0.466}Sc^{-0.528}$

Note: Ac = contributing drainage area (mi^2).
Sc = main channel slope (ft/mi).
Bs = basin shape index which is the ratio of basin length (mi^2) to total drainage area (mi^2)
Ss = main channel sinuosity which is the ratio of main channel length to basin length.

an interconnected system of hydrologic and hydraulic components. The model consists of a number of components which model various aspects of the precipitation-runoff process within a portion of the watershed (i.e., subbasin). Components may represent surface runoff, stream channel, or a reservoir. Representation of a component requires a set of parameters which specify the particular aspects of the component and the mathematical relations which describe the physical processes. The result is a computation of streamflow hydrographs at desired locations in the watershed.

HEC-1 can be run for a variety of uses (e.g., computing rainfall distributions for storms of varying duration; performing infiltration loss computations; generating unit hydrographs for the watershed; computing excess rainfall and complete runoff hydrographs; and combining hydrographs from different watersheds); however, the primary use pertaining to wetlands is the routing of a hydrograph downstream through a stream channel to evaluate the effects of travel time and temporary storage on the hydrograph. As with the previous two methods of determining flood recurrence intervals, the HEC-1 model output is in terms of water discharge or flow and not water stage or height. Another hydraulic computer program can be used in conjunction with HEC-1 to determine stage (Claborn and Dodson 1992).

The HEC-1 model represents a widely used and reasonably accurate model of stream flow following a given storm event. However, it may not be suitable for use in rapid wetland assessment because of its intense data requirements. For instance, rainfall records are needed to estimate the amount of precipitation in a given storm event. Estimates for losses of this rainfall to soil infiltration, interception, depression and surface storage, interflow, and evaporation all need to be accounted for in the model inputs. The runoff is then calculated by subtracting the losses from the rainfall input. This excess water produces runoff which must then be "routed" to the basin outlet where it appears as the outflow hydrograph. This result requires extensive data input, computer software, and hydrologic expertise to run and interpret the model outputs.

Regional dimensionless rating curves

A technique which can be used to estimate the frequency and depth at which a given flood event occurs is to develop a regional dimensionless rating curve (Figure C5). This curve is based on the relation between channel depth and discharge, similar to rating curves constructed by USGS for gaged streams. However, this curve is "dimensionless" because it compares the ratio of channel-full depth and bankfull depth to the ratio of the flow at channel full and bankfull. These terms are defined and discussed below. Construction of a regional dimensionless rating curve is discussed in Dunne and Leopold (1978), Leopold (1994), and Pruitt and Nutter (unpublished manuscript).

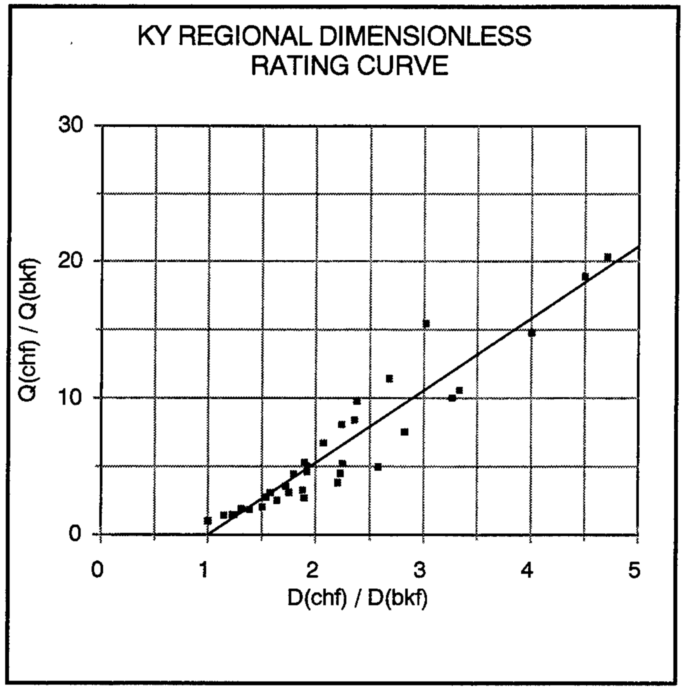


Figure C5. Regional dimensionless rating curve comparing ratios of depth and discharge (R^2= 0.94)

The regional dimensionless rating curve can be used to estimate a typical discharge associated with an overbank event based on the ratio of channel-full depth to bankfull depth in similar watersheds within a region (Dunne and Leopold 1978, Leopold 1994). Channel-full depth (D_{CHF}) is the average vertical distance from the bottom of the channel to the top of the stream bank (Figure C6) (Puitt and Nutter unpublished manuscript). Bankfull depth (D_{BKF}) is the average vertical distance from the bottom of the channel to the point on the stream bank where indicators of bankfull discharge are apparent. Bankfull indicators in western Kentucky are: (a) vegetation changes from annual plant cover to perennial/woody plant cover which form a line on both right and left banks and (b) areas of active deposition (laterally or vertically accreting surfaces). Channel-full discharge (Q_{CHF}) is the discharge required to reach the average channel-full depth. Bankfull discharge (Q_{BKF}) is the discharge required to reach the average bankfull depth. The dimensionless rating curve compares the ratios of average channel-full depth to average bankfull depth (D_{CHF}/D_{BKF}) and channel-full discharge to bankfull discharge (Q_{CHF}/Q_{BKF}).

A dimensionless rating curve was developed for western Kentucky using the methods described in Pruitt and Nutter (unpublished manuscript). Use of this dimensionless rating curve to determine return interval is described in the five steps that follow. The following assumptions are made in this determination:

a. Channel depth measurements obtained at bridge crossings are representative of channel depths adjacent to the wetland area being assessed.

b. Bridges are level.

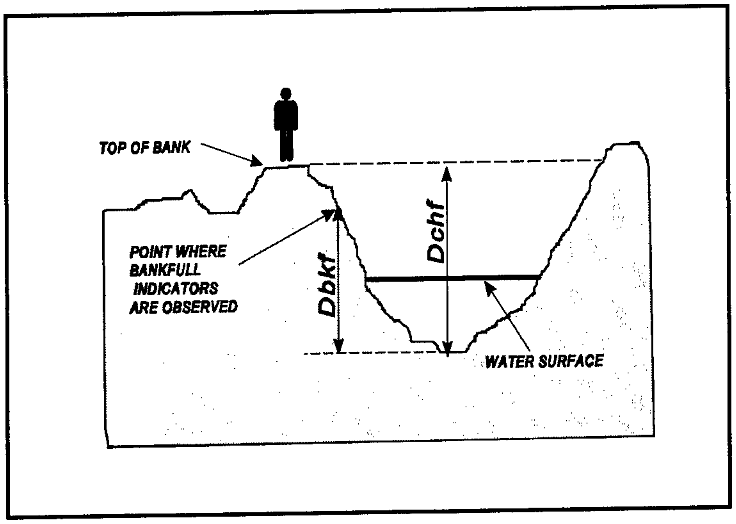


Figure C6. Relationship between channel-full depth (D_{CHF}), the elevation along the stream bank at which inundation of the wetland surface occurs, and bankfull depth (D_{BKF}) where bankfull indicators are observed (Pruitt and Nutter unpublished manuscript.)

c. Water surface elevations are essentially the same at the bridge crossing and the channel adjacent to the wetland area being assessed.

Step 1. The first step is to determine the average channel-full depth (D_{CHF}) using a weighted tape measure at a nearby bridge crossing. Determine the vertical distance from a prescribed point on the bridge to:

a. The top of the stream bank.

b. The water surface in the stream channel.

c. The bottom of the stream channel (Figure C6).

The distance to the water surface is the datum to which the distance to the top of the stream bank and the bottom of the channel are compared. The difference between average distance to the top of the stream bank and the average distance to bottom of the stream channel is channel-full depth (D_{CHF}). For example, if the distance from the prescribed point on the bridge to the top of the stream bank is 10 m (32.8 ft), and the distance from the prescribed point on the bridge to the bottom of the stream channel is 13 m (42.7 ft), then channel-full depth (i.e., top of the stream bank to the bottom of the channel) is 3 m (9.8 ft) at that point. To obtain the "average channel-full depth", average the difference between the two measurements at 6-m (19.6-ft) intervals from the edge of the water at one bank to the edge of the water at the opposite bank. Channels less than 30 m (98.4 ft) wide will require at least 5 measurements, and channels wider than 30 m (98.4 ft) will require at least 1 additional measurement for each additional 6 m (20 ft) in width.

The average channel-full depth calculated for the bridge crossing may have to be adjusted to reflect the elevation at which water from the stream channel actually inundates the riverine wetland being assessed. For example, low points in a natural levee that are created by tributaries or other erosive forces will often allow water to inundate riverine wetlands before water overtops the bank along a stream reach. The water surface datum determined at the bridge crossing is used to make this adjustment. For instance, using the example above, assume that the distance from the top of the bank to the water surface at the bridge is 1 m (3.3 ft) and the distance from the water surface to the bottom of the channel is 2 m (6.6 ft). If the distance from the top of the bank to the water surface adjacent to the area being assessed is 0.5 m (1.6 ft), which is 0.5 m (1.6 ft) less than at the bridge, then the adjusted average channel-full depth (D_{CHF}) used to determine return interval is 2.5 m (8.2 ft) rather than the 3 m (9.8 ft) determined at the bridge crossing.

Step 2. The second step is to determine average bankfull depth (D_{BKF}) by either: (a) estimating average bankfull depth based on the relationship between drainage basin size and bankfull depth shown in Figure C7 (for example, a stream with a drainage basin of 100 mi^2 has a corresponding bankfull depth of 1.7 m (5.6 ft.). Average bankfull depth can also be calculated as: [$D_{BKF} = 0.49 \times$ (drainage area $^{0.53)}$)]) or (b) measuring the height of bankfull indicators (Harrelson, Rawlins, and Potyondy 1994) (described above) above the thalweg (i.e., the deepest part of the channel) and surveying a channel cross section to determine average bankfull depth.

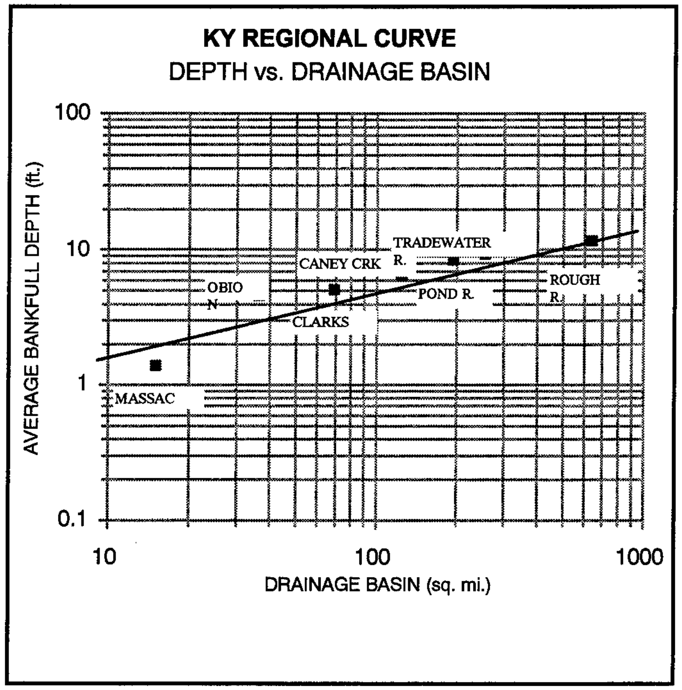


Figure C7. Regional curve comparing average bankfull depth (D_{BKF}) to drainage area ($R^2 = 0.88$)

Step 3. The third step is to estimate bankfull discharge (Q_{BKF}) using the relationship between bankfull discharge and drainage basin size shown in Figure C8. The bankfull discharge can also be calculated as: [$Q_{BKF} = 1.46 \times$ (drainage area$^{1.34}$)]. For example, a drainage basin of 100 mi^2 has a corresponding bankfull discharge (Q_{BKF}) of 699 cfs.

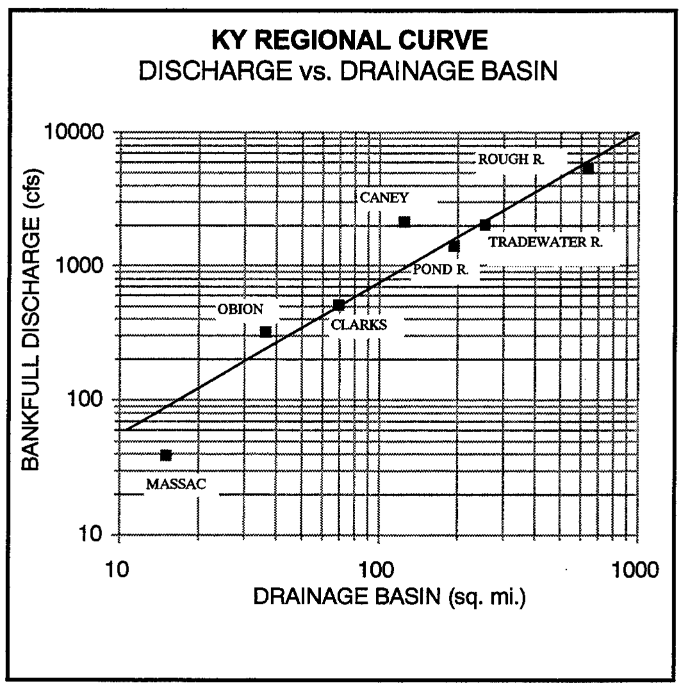


Figure C8. Regional curve comparing average bankfull discharge (Q_{BKF}) to drainage area ($R^2 = 0.88$)

Step 4. The fourth step is to determine channel-full discharge (Q_{CHF}). This is done using the calculated values of channel-full depth (D_{CHF}) and bankfull depth (D_{BKF}) and bankfull flow (Q_{BKF}) from steps 1, 2, and 3 above and the regional dimensionless curve. For example, if channel-full depth (D_{CHF}) is 10 ft, and bankfull depth (D_{BKF}) is 8.0 ft then the ratio of D_{CHF}/D_{BKF} is 10 / 8.0 = 1.25. The bankfull flow (Q_{BKF}) is 699 cfs. An alternative method for determining the dis-charge is to use the following regression equation developed for this specific watershed:

Table C3
Channel-Full Flow Values (Q_{CHF}) Using D_{CHF}/D_{BKF} Ratio and Q_{BKF}

	D_{CHF}/D_{BKF} Ratio										
Q_{BKF}	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2	2.1
50	1	31.5	62	92.5	123	153.5	184	214.5	245	275.5	306
100	2	63	124	185	246	307	368	429	490	551	612
150	3	94.5	186	277.5	369	460.5	552	643.5	735	826.5	918
200	4	126	248	370	492	614	736	858	980	1102	1224
250	5	157.5	310	462.5	615	767.5	920	1072.5	1225	1377.5	1530
300	6	189	372	555	738	921	1104	1287	1470	1653	1836
350	7	220.5	434	647.5	861	1074.5	1288	1501.5	1715	1928.5	2142
400	8	252	496	740	984	1228	1472	1716	1960	2204	2448
450	9	283.5	558	832.5	1107	1381.5	1656	1930.5	2205	2479.5	2754
500	10	315	620	925	1230	1535	1840	2145	2450	2755	3060
550	11	346.5	682	1017.5	1353	1688.5	2024	2359.5	2695	3030.5	3366
600	12	378	744	1110	1476	1842	2208	2574	2940	3306	3672
650	13	409.5	806	1202.5	1599	1995.5	2392	2788.5	3185	3581.5	3978
700	14	441	868	1295	1722	2149	2576	3003	3430	3857	4284
750	15	472.5	930	1387.5	1845	2302.5	2760	3217.5	3675	4132.5	4590
800	16	504	992	1480	1968	2456	2944	3432	3920	4408	4896
850	17	535.5	1054	1572.5	2091	2609.5	3128	3646.5	4165	4683.5	5202
900	18	567	1116	1665	2214	2763	3312	3861	4410	4959	5508
950	19	598.5	1178	1757.5	2337	2916.5	3496	4075.5	4655	5234.5	5814
1000	20	630	1240	1850	2460	3070	3680	4290	4900	5510	6120
1050	21	661.5	1302	1942.5	2583	3223.5	3864	4504.5	5145	5785.5	6426
1100	22	693	1364	2035	2706	3377	4048	4719	5390	6061	6732
1150	23	724.5	1426	2127.5	2829	3530.5	4232	4933.5	5635	6336.5	7038
1200	24	756	1488	2220	2952	3684	4416	5148	5880	6612	7344
1250	25	787.5	1550	2312.5	3075	3837.5	4600	5362.5	6125	6887.5	7650
1300	26	819	1612	2405	3198	3991	4784	5577	6370	7163	7956
1350	27	850.5	1674	2497.5	3321	4144.5	4968	5791.5	6615	7438.5	8262
1400	28	882	1736	2590	3444	4298	5152	6006	6860	7714	8568
1450	29	913.5	1798	2682.5	3567	4451.5	5336	6220.5	7105	7989.5	8874
1500	30	945	1860	2775	3690	4605	5520	6435	7350	8265	9180
1550	31	976.5	1922	2867.5	3813	4758.5	5704	6649.5	7595	8540.5	9486
1600	32	1008	1984	2960	3936	4912	5888	6864	7840	8816	9792
1650	33	1039.5	2046	3052.5	4059	5065.5	6072	7078.5	8085	9091.5	10098
1700	34	1071	2108	3145	4182	5219	6256	7293	8330	9367	10404
1750	35	1102.5	2170	3237.5	4305	5372.5	6440	7507.5	8575	9642.5	10710
1800	36	1134	2232	3330	4428	5526	6624	7722	8820	9918	11016
1850	37	1165.5	2294	3422.5	4551	5679.5	6808	7936.5	9065	10193	11322
1900	38	1197	2356	3515	4674	5833	6992	8151	9310	10469	11628
1950	39	1228.5	2418	3607.5	4797	5986.5	7176	8365.5	9555	10744	11934

(Sheet 1 of 20)

Table C3 (Continued)

	D_{CHF}/D_{BKF} Ratio										
Q_{BKF}	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2	2.1
2000	40	1260	2480	3700	4920	6140	7360	8580	9800	11020	12240
2050	41	1291.5	2542	3792.5	5043	6293.5	7544	8794.5	10045	11295	12546
2100	42	1323	2604	3885	5166	6447	7728	9009	10290	11571	12852
2150	43	1354.5	2666	3977.5	5289	6600.5	7912	9223.5	10535	11846	13158
2200	44	1386	2728	4070	5412	6754	8096	9438	10780	12122	13464
2250	45	1417.5	2790	4162.5	5535	6907.5	8280	9652.5	11025	12397	13770
2300	46	1449	2852	4255	5658	7061	8464	9867	11270	12673	14076
2350	47	1480.5	2914	4347.5	5781	7214.5	8648	10082	11515	12948	14382
2400	48	1512	2976	4440	5904	7368	8832	10296	11760	13224	14688
2450	49	1543.5	3038	4532.5	6027	7521.5	9016	10511	12005	13499	14994
2500	50	1575	3100	4625	6150	7675	9200	10725	12250	13775	15300
2550	51	1606.5	3162	4717.5	6273	7828.5	9384	10940	12495	14050	15606
2600	52	1638	3224	4810	6396	7982	9568	11154	12740	14326	15912
2650	53	1669.5	3286	4902.5	6519	8135.5	9752	11369	12985	14601	16218
2700	54	1701	3348	4995	6642	8289	9936	11583	13230	14877	16524
2750	55	1732.5	3410	5087.5	6765	8442.5	10120	11798	13475	15152	16830
2800	56	1764	3472	5180	6888	8596	10304	12012	13720	15428	17136
2850	57	1795.5	3534	5272.5	7011	8749.5	10488	12227	13965	15703	17442
2900	58	1827	3596	5365	7134	8903	10672	12441	14210	15979	17748
2950	59	1858.5	3658	5457.5	7257	9056.5	10856	12656	14455	16254	18054
3000	60	1890	3720	5550	7380	9210	11040	12870	14700	16530	18360
3050	61	1921.5	3782	5642.5	7503	9363.5	11224	13085	14945	16805	18666
3100	62	1953	3844	5735	7626	9517	11408	13299	15190	17081	18972
3150	63	1984.5	3906	5827.5	7749	9670.5	11592	13514	15435	17356	19278
3200	64	2016	3968	5920	7872	9824	11776	13728	15680	17632	19584
3250	65	2047.5	4030	6012.5	7995	9977.5	11960	13943	15925	17907	19890
3300	66	2079	4092	6105	8118	10131	12144	14157	16170	18183	20196
3350	67	2110.5	4154	6197.5	8241	10284	12328	14372	16415	18458	20502
3400	68	2142	4216	6290	8364	10438	12512	14586	16660	18734	20808
3450	69	2173.5	4278	6382.5	8487	10591	12696	14801	16905	19009	21114
3500	70	2205	4340	6475	8610	10745	12880	15015	17150	19285	21420
3550	71	2236.5	4402	6567.5	8733	10898	13064	15230	17395	19560	21726
3600	72	2268	4464	6660	8856	11052	13248	15444	17640	19836	22032
3650	73	2299.5	4526	6752.5	8979	11205	13432	15659	17885	20111	22338
3700	74	2331	4588	6845	9102	11359	13616	15873	18130	20387	22644
3750	75	2362.5	4650	6937.5	9225	11512	13800	16088	18375	20662	22950
3800	76	2394	4712	7030	9348	11666	13984	16302	18620	20938	23256
3850	77	2425.5	4774	7122.5	9471	11819	14168	16517	18865	21213	23562
3900	78	2457	4836	7215	9594	11973	14352	16731	19110	21489	23868
3950	79	2488.5	4898	7307.5	9717	12126	14536	16946	19355	21764	24174

(Sheet 2 of 20)

Table C3 (Continued)

	D_{CHF}/D_{BKF} Ratio										
Q_{BKF}	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2	2.1
4000	80	2520	4960	7400	9840	12280	14720	17160	19600	22040	24480
4050	81	2551.5	5022	7492.5	9963	12433	14904	17375	19845	22315	24786
4100	82	2583	5084	7585	10086	12587	15088	17589	20090	22591	25092
4150	83	2614.5	5146	7677.5	10209	12740	15272	17804	20335	22866	25398
4200	84	2646	5208	7770	10332	12894	15456	18018	20580	23142	25704
4250	85	2677.5	5270	7862.5	10455	13047	15640	18233	20825	23417	26010
4300	86	2709	5332	7955	10578	13201	15824	18447	21070	23693	26316
4350	87	2740.5	5394	8047.5	10701	13354	16008	18662	21315	23968	26622
4400	88	2772	5456	8140	10824	13508	16192	18876	21560	24244	26928
4450	89	2803.5	5518	8232.5	10947	13661	16376	19091	21805	24519	27234
4500	90	2835	5580	8325	11070	13815	16560	19305	22050	24795	27540
4550	91	2866.5	5642	8417.5	11193	13968	16744	19520	22295	25070	27846
4600	92	2898	5704	8510	11316	14122	16928	19734	22540	25346	28152
4650	93	2929.5	5766	8602.5	11439	14275	17112	19949	22785	25621	28458
4700	94	2961	5828	8695	11562	14429	17296	20163	23030	25897	28764
4750	95	2992.5	5890	8787.5	11685	14582	17480	20378	23275	26172	29070
4800	96	3024	5952	8880	11808	14736	17664	20592	23520	26448	29376
4850	97	3055.5	6014	8972.5	11931	14889	17848	20807	23765	26723	29682
4900	98	3087	6076	9065	12054	15043	18032	21021	24010	26999	29988
4950	99	3118.5	6138	9157.5	12177	15196	18216	21236	24255	27274	30294
5000	100	3150	6200	9250	12300	15350	18400	21450	24500	27550	30600
5050	101	3181.5	6262	9342.5	12423	15503	18584	21665	24745	27825	30906
5100	102	3213	6324	9435	12546	15657	18768	21879	24990	28101	31212
5150	103	3244.5	6386	9527.5	12669	15810	18952	22094	25235	28376	31518
5200	104	3276	6448	9620	12792	15964	19136	22308	25480	28652	31824
5250	105	3307.5	6510	9712.5	12915	16117	19320	22523	25725	28927	32130
5300	106	3339	6572	9805	13038	16271	19504	22737	25970	29203	32436
5350	107	3370.5	6634	9897.5	13161	16424	19688	22952	26215	29478	32742
5400	108	3402	6696	9990	13284	16578	19872	23166	26460	29754	33048
5450	109	3433.5	6758	10082	13407	16731	20056	23381	26705	30029	33354
5500	110	3465	6820	10175	13530	16885	20240	23595	26950	30305	33660
5550	111	3496.5	6882	10267	13653	17038	20424	23810	27195	30580	33966
5600	112	3528	6944	10360	13776	17192	20608	24024	27440	30856	34272
5650	113	3559.5	7006	10452	13899	17345	20792	24239	27685	31131	34578
5700	114	3591	7068	10545	14022	17499	20976	24453	27930	31407	34884
5750	115	3622.5	7130	10637	14145	17652	21160	24668	28175	31682	35190
5800	116	3654	7192	10730	14268	17806	21344	24882	28420	31958	35496
5850	117	3685.5	7254	10822	14391	17959	21528	25097	28665	32233	35802
5900	118	3717	7316	10915	14514	18113	21712	25311	28910	32509	36108
5950	119	3748.5	7378	11007	14637	18266	21896	25526	29155	32784	36414

(Sheet 3 of 20)

Table C3 (Continued)

	D_{CHP}/D_{BKF} Ratio										
Q_{BKF}	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2	2.1
6000	120	3780	7440	11100	14760	18420	22080	25740	29400	33060	36720
6050	121	3811.5	7502	11192	14883	18573	22264	25955	29645	33335	37026
6100	122	3843	7564	11285	15006	18727	22448	26169	29890	33611	37332
6150	123	3874.5	7626	11377	15129	18880	22632	26384	30135	33886	37638
6200	124	3906	7688	11470	15252	19034	22816	26598	30380	34162	37944
6250	125	3937.5	7750	11562	15375	19187	23000	26813	30625	34437	38250
6300	126	3969	7812	11655	15498	19341	23184	27027	30870	34713	38556
6350	127	4000.5	7874	11747	15621	19494	23368	27242	31115	34988	38862
6400	128	4032	7936	11840	15744	19648	23552	27456	31360	35264	39168
6450	129	4063.5	7998	11932	15867	19801	23736	27671	31605	35539	39474
6500	130	4095	8060	12025	15990	19955	23920	27885	31850	35815	39780
6550	131	4126.5	8122	12117	16113	20108	24104	28100	32095	36090	40086
6600	132	4158	8184	12210	16236	20262	24288	28314	32340	36366	40392
6650	133	4189.5	8246	12302	16359	20415	24472	28529	32585	36641	40698
6700	134	4221	8308	12395	16482	20569	24656	28743	32830	36917	41004
6750	135	4252.5	8370	12487	16605	20722	24840	28958	33075	37192	41310
6800	136	4284	8432	12580	16728	20876	25024	29172	33320	37468	41616
6850	137	4315.5	8494	12672	16851	21029	25208	29387	33565	37743	41922
6900	138	4347	8556	12765	16974	21183	25392	29601	33810	38019	42228
6950	139	4378.5	8618	12857	17097	21336	25576	29816	34055	38294	42534
7000	140	4410	8680	12950	17220	21490	25760	30030	34300	38570	42840
7050	141	4441.5	8742	13042	17343	21643	25944	30245	34545	38845	43146
7100	142	4473	8804	13135	17466	21797	26128	30459	34790	39121	43452
7150	143	4504.5	8866	13227	17589	21950	26312	30674	35035	39396	43758
7200	144	4536	8928	13320	17712	22104	26496	30888	35280	39672	44064
7250	145	4567.5	8990	13412	17835	22257	26680	31103	35525	39947	44370
7300	146	4599	9052	13505	17958	22411	26864	31317	35770	40223	44676
7350	147	4630.5	9114	13597	18081	22564	27048	31532	36015	40498	44982
7400	148	4662	9176	13690	18204	22718	27232	31746	36260	40774	45288
7450	149	4693.5	9238	13782	18327	22871	27416	31961	36505	41049	45594
7500	150	4725	9300	13875	18450	23025	27600	32175	36750	41325	45900
7550	151	4756.5	9362	13967	18573	23178	27784	32390	36995	41600	46206
7600	152	4788	9424	14060	18696	23332	27968	32604	37240	41876	46512
7650	153	4819.5	9486	14152	18819	23485	28152	32819	37485	42151	46818
7700	154	4851	9548	14245	18942	23639	28336	33033	37730	42427	47124
7750	155	4882.5	9610	14337	19065	23792	28520	33248	37975	42702	47430
7800	156	4914	9672	14430	19188	23946	28704	33462	38220	42978	47736
7850	157	4945.5	9734	14522	19311	24099	28888	33677	38465	43253	48042
7900	158	4977	9796	14615	19434	24253	29072	33891	38710	43529	48348
7950	159	5008.5	9858	14707	19557	24406	29256	34106	38955	43804	48654
8000	160	5040	9920	14800	19680	24560	29440	34320	39200	44080	48960

(Sheet 4 of 20)

Table C3 (Continued)

	D_{CHP}/D_{BKF} Ratio										
Q_{BKF}	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2	2.1
8050	161	5071.5	9982	14892	19803	24713	29624	34535	39445	44355	49266
8100	162	5103	10044	14985	19926	24867	29808	34749	39690	44631	49572
8150	163	5134.5	10106	15077	20049	25020	29992	34964	39935	44906	49878
8200	164	5166	10168	15170	20172	25174	30176	35178	40180	45182	50184
8250	165	5197.5	10230	15262	20295	25327	30360	35393	40425	45457	50490
8300	166	5229	10292	15355	20418	25481	30544	35607	40670	45733	50796
8350	167	5260.5	10354	15447	20541	25634	30728	35822	40915	46008	51102
8400	168	5292	10416	15540	20664	25788	30912	36036	41160	46284	51408
8450	169	5323.5	10478	15632	20787	25941	31096	36251	41405	46559	51714
8500	170	5355	10540	15725	20910	26095	31280	36465	41650	46835	52020
8550	171	5386.5	10602	15817	21033	26248	31464	36680	41895	47110	52326
8600	172	5418	10664	15910	21156	26402	31648	36894	42140	47386	52632
8650	173	5449.5	10726	16002	21279	26555	31832	37109	42385	47661	52938
8700	174	5481	10788	16095	21402	26709	32016	37323	42630	47937	53244
8750	175	5512.5	10850	16187	21525	26862	32200	37538	42875	48212	53550
8800	176	5544	10912	16280	21648	27016	32384	37752	43120	48488	53856
8850	177	5575.5	10974	16372	21771	27169	32568	37967	43365	48763	54162
8900	178	5607	11036	16465	21894	27323	32752	38181	43610	49039	54468
8950	179	5638.5	11098	16557	22017	27476	32936	38396	43855	49314	54774
9000	180	5670	11160	16650	22140	27630	33120	38610	44100	49590	55080
9050	181	5701.5	11222	16742	22263	27783	33304	38825	44345	49865	55386
9100	182	5733	11284	16835	22386	27937	33488	39039	44590	50141	55692
9150	183	5764.5	11346	16927	22509	28090	33672	39254	44835	50416	55998
9200	184	5796	11408	17020	22632	28244	33856	39468	45080	50692	56304
9250	185	5827.5	11470	17112	22755	28397	34040	39683	45325	50967	56610
9300	186	5859	11532	17205	22878	28551	34224	39897	45570	51243	56916
9350	187	5890.5	11594	17297	23001	28704	34408	40112	45815	51518	57222
9400	188	5922	11656	17390	23124	28858	34592	40326	46060	51794	57528
9450	189	5953.5	11718	17482	23247	29011	34776	40541	46305	52069	57834
9500	190	5985	11780	17575	23370	29165	34960	40755	46550	52345	58140
9550	191	6016.5	11842	17667	23493	29318	35144	40970	46795	52620	58446
9600	192	6048	11904	17760	23616	29472	35328	41184	47040	52896	58752
9650	193	6079.5	11966	17852	23739	29625	35512	41399	47285	53171	59058
9700	194	6111	12028	17945	23862	29779	35696	41613	47530	53447	59364
9750	195	6142.5	12090	18037	23985	29932	35880	41828	47775	53722	59670
9800	196	6174	12152	18130	24108	30086	36064	42042	48020	53998	59976
9850	197	6205.5	12214	18222	24231	30239	36248	42257	48265	54273	60282
9900	198	6237	12276	18315	24354	30393	36432	42471	48510	54549	60588
9950	199	6268.5	12338	18407	24477	30546	36616	42686	48755	54824	60894
10000	200	6300	12400	18500	24600	30700	36800	42900	49000	55100	61200

(Sheet 5 of 20)

Table C3 (Continued)

	D_{CHF}/D_{BKF} Ratio										
Q_{BKF}	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3	3.1	3.2
50	336.5	367	397.5	428	458.5	489	519.5	550	580.5	611	641.5
100	673	734	795	856	917	978	1039	1100	1161	1222	1283
150	1009.5	1101	1192.5	1284	1375.5	1467	1558.5	1650	1741.5	1833	1924.5
200	1346	1468	1590	1712	1834	1956	2078	2200	2322	2444	2566
250	1682.5	1835	1987.5	2140	2292.5	2445	2597.5	2750	2902.5	3055	3207.5
300	2019	2202	2385	2568	2751	2934	3117	3300	3483	3666	3849
350	2355.5	2569	2782.5	2996	3209.5	3423	3636.5	3850	4063.5	4277	4490.5
400	2692	2936	3180	3424	3668	3912	4156	4400	4644	4888	5132
450	3028.5	3303	3577.5	3852	4126.5	4401	4675.5	4950	5224.5	5499	5773.5
500	3365	3670	3975	4280	4585	4890	5195	5500	5805	6110	6415
550	3701.5	4037	4372.5	4708	5043.5	5379	5714.5	6050	6385.5	6721	7056.5
600	4038	4404	4770	5136	5502	5868	6234	6600	6966	7332	7698
650	4374.5	4771	5167.5	5564	5960.5	6357	6753.5	7150	7546.5	7943	8339.5
700	4711	5138	5565	5992	6419	6846	7273	7700	8127	8554	8981
750	5047.5	5505	5962.5	6420	6877.5	7335	7792.5	8250	8707.5	9165	9622.5
800	5384	5872	6360	6848	7336	7824	8312	8800	9288	9776	10264
850	5720.5	6239	6757.5	7276	7794.5	8313	8831.5	9350	9868.5	10387	10905
900	6057	6606	7155	7704	8253	8802	9351	9900	10449	10998	11547
950	6393.5	6973	7552.5	8132	8711.5	9291	9870.5	10450	11029	11609	12188
1000	6730	7340	7950	8560	9170	9780	10390	11000	11610	12220	12830
1050	7066.5	7707	8347.5	8988	9628.5	10269	10909	11550	12190	12831	13471
1100	7403	8074	8745	9416	10087	10758	11429	12100	12771	13442	14113
1150	7739.5	8441	9142.5	9844	10545	11247	11948	12650	13351	14053	14754
1200	8076	8808	9540	10272	11004	11736	12468	13200	13932	14664	15396
1250	8412.5	9175	9937.5	10700	11462	12225	12987	13750	14512	15275	16037
1300	8749	9542	10335	11128	11921	12714	13507	14300	15093	15886	16679
1350	9085.5	9909	10732	11556	12379	13203	14026	14850	15673	16497	17320
1400	9422	10276	11130	11984	12838	13692	14546	15400	16254	17108	17962
1450	9758.5	10643	11527	12412	13296	14181	15065	15950	16834	17719	18603
1500	10095	11010	11925	12840	13755	14670	15585	16500	17415	18330	19245
1550	10432	11377	12322	13268	14213	15159	16104	17050	17995	18941	19886
1600	10768	11744	12720	13696	14672	15648	16624	17600	18576	19552	20528
1650	11105	12111	13117	14124	15130	16137	17143	18150	19156	20163	21169
1700	11441	12478	13515	14552	15589	16626	17663	18700	19737	20774	21811
1750	11778	12845	13912	14980	16047	17115	18182	19250	20317	21385	22452
1800	12114	13212	14310	15408	16506	17604	18702	19800	20898	21996	23094
1850	12451	13579	14707	15836	16964	18093	19221	20350	21478	22607	23735
1900	12787	13946	15105	16264	17423	18582	19741	20900	22059	23218	24377
1950	13124	14313	15502	16692	17881	19071	20260	21450	22639	23829	25018
2000	13460	14680	15900	17120	18340	19560	20780	22000	23220	24440	25660
2050	13796	15047	16297	17548	18798	20049	21299	22550	23800	25051	26301

(Sheet 6 of 20)

Table C3 (Continued)

	D_{CHP}/D_{BKF} Ratio										
Q_{BKF}	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3	3.1	3.2
2100	14133	15414	16695	17976	19257	20538	21819	23100	24381	25662	26943
2150	14469	15781	17092	18404	19715	21027	22338	23650	24961	26273	27584
2200	14806	16148	17490	18832	20174	21516	22858	24200	25542	26884	28226
2250	15142	16515	17887	19260	20632	22005	23377	24750	26122	27495	28867
2300	15479	16882	18285	19688	21091	22494	23897	25300	26703	28106	29509
2350	15815	17249	18682	20116	21549	22983	24416	25850	27283	28717	30150
2400	16152	17616	19080	20544	22008	23472	24936	26400	27864	29328	30792
2450	16489	17983	19477	20972	22466	23961	25455	26950	28444	29939	31433
2500	16825	18350	19875	21400	22925	24450	25975	27500	29025	30550	32075
2550	17162	18717	20272	21828	23383	24939	26494	28050	29605	31161	32716
2600	17498	19084	20670	22256	23842	25428	27014	28600	30186	31772	33358
2650	17835	19451	21067	22684	24300	25917	27533	29150	30766	32383	33999
2700	18171	19818	21465	23112	24759	26406	28053	29700	31347	32994	34641
2750	18508	20185	21862	23540	25217	26895	28572	30250	31927	33605	35282
2800	18844	20552	22260	23968	25676	27384	29092	30800	32508	34216	35924
2850	19181	20919	22657	24396	26134	27873	29611	31350	33088	34827	36565
2900	19517	21286	23055	24824	26593	28362	30131	31900	33669	35438	37207
2950	19854	21653	23452	25252	27051	28851	30650	32450	34249	36049	37848
3000	20190	22020	23850	25680	27510	29340	31170	33000	34830	36660	38490
3050	20527	22387	24247	26108	27968	29829	31689	33550	35410	37271	39131
3100	20863	22754	24645	26536	28427	30318	32209	34100	35991	37882	39773
3150	21200	23121	25042	26964	28885	30807	32728	34650	36571	38493	40414
3200	21536	23488	25440	27392	29344	31296	33248	35200	37152	39104	41056
3250	21873	23855	25837	27820	29802	31785	33767	35750	37732	39715	41697
3300	22209	24222	26235	28248	30261	32274	34287	36300	38313	40326	42339
3350	22546	24589	26632	28676	30719	32763	34806	36850	38893	40937	42980
3400	22882	24956	27030	29104	31178	33252	35326	37400	39474	41548	43622
3450	23219	25323	27427	29532	31636	33741	35845	37950	40054	42159	44263
3500	23555	25690	27825	29960	32095	34230	36365	38500	40635	42770	44905
3550	23892	26057	28222	30388	32553	34719	36884	39050	41215	43381	45546
3600	24228	26424	28620	30816	33012	35208	37404	39600	41796	43992	46188
3650	24565	26791	29017	31244	33470	35697	37923	40150	42376	44603	46829
3700	24901	27158	29415	31672	33929	36186	38443	40700	42957	45214	47471
3750	25238	27525	29812	32100	34387	36675	38962	41250	43537	45825	48112
3800	25574	27892	30210	32528	34846	37164	39482	41800	44118	46436	48754
3850	25911	28259	30607	32956	35304	37653	40001	42350	44698	47047	49395
3900	26247	28626	31005	33384	35763	38142	40521	42900	45279	47658	50037
3950	26583	28993	31402	33812	36221	38631	41040	43450	45859	48269	50678
4000	26920	29360	31800	34240	36680	39120	41560	44000	46440	48880	51320
4050	27256	29727	32197	34668	37138	39609	42079	44550	47020	49491	51961

(Sheet 7 of 20)

Table C3 (Continued)											
	D_{CHF}/D_{BKF} Ratio										
Q_{BKF}	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3	3.1	3.2
4100	27593	30094	32595	35096	37597	40098	42599	45100	47601	50102	52603
4150	27929	30461	32992	35524	38055	40587	43118	45650	48181	50713	53244
4200	28266	30828	33390	35952	38514	41076	43638	46200	48762	51324	53886
4250	28602	31195	33787	36380	38972	41565	44157	46750	49342	51935	54527
4300	28939	31562	34185	36808	39431	42054	44677	47300	49923	52546	55169
4350	29275	31929	34582	37236	39889	42543	45196	47850	50503	53157	55810
4400	29612	32296	34980	37664	40348	43032	45716	48400	51084	53768	56452
4450	29948	32663	35377	38092	40806	43521	46235	48950	51664	54379	57093
4500	30285	33030	35775	38520	41265	44010	46755	49500	52245	54990	57735
4550	30621	33397	36172	38948	41723	44499	47274	50050	52825	55601	58376
4600	30958	33764	36570	39376	42182	44988	47794	50600	53406	56212	59018
4650	31294	34131	36967	39804	42640	45477	48313	51150	53986	56823	59659
4700	31631	34498	37365	40232	43099	45966	48833	51700	54567	57434	60301
4750	31967	34865	37762	40660	43557	46455	49352	52250	55147	58045	60942
4800	32304	35232	38160	41088	44016	46944	49872	52800	55728	58656	61584
4850	32640	35599	38557	41516	44474	47433	50391	53350	56308	59267	62225
4900	32977	35966	38955	41944	44933	47922	50911	53900	56889	59878	62867
4950	33314	36333	39352	42372	45391	48411	51430	54450	57469	60489	63508
5000	33650	36700	39750	42800	45850	48900	51950	55000	58050	61100	64150
5050	33987	37067	40147	43228	46308	49389	52469	55550	58630	61711	64791
5100	34323	37434	40545	43656	46767	49878	52989	56100	59211	62322	65433
5150	34660	37801	40942	44084	47225	50367	53508	56650	59791	62933	66074
5200	34996	38168	41340	44512	47684	50856	54028	57200	60372	63544	66716
5250	35333	38535	41737	44940	48142	51345	54547	57750	60952	64155	67357
5300	35669	38902	42135	45368	48601	51834	55067	58300	61533	64766	67999
5350	36006	39269	42532	45796	49059	52323	55586	58850	62113	65377	68640
5400	36342	39636	42930	46224	49518	52812	56106	59400	62694	65988	69282
5450	36679	40003	43327	46652	49976	53301	56625	59950	63274	66599	69923
5500	37015	40370	43725	47080	50435	53790	57145	60500	63855	67210	70565
5550	37352	40737	44122	47508	50893	54279	57664	61050	64435	67821	71206
5600	37688	41104	44520	47936	51352	54768	58184	61600	65016	68432	71848
5650	38025	41471	44917	48364	51810	55257	58703	62150	65596	69043	72489
5700	38361	41838	45315	48792	52269	55746	59223	62700	66177	69654	73131
5750	38698	42205	45712	49220	52727	56235	59742	63250	66757	70265	73772
5800	39034	42572	46110	49648	53186	56724	60262	63800	67338	70876	74414
5850	39371	42939	46507	50076	53644	57213	60781	64350	67918	71487	75055
5900	39707	43306	46905	50504	54103	57702	61301	64900	68499	72098	75697
5950	40044	43673	47302	50932	54561	58191	61820	65450	69079	72709	76338
6000	40380	44040	47700	51360	55020	58680	62340	66000	69660	73320	76980
6050	40717	44407	48097	51788	55478	59169	62859	66550	70240	73931	77621
6100	41053	44774	48495	52216	55937	59658	63379	67100	70821	74542	78263
											(Sheet 8 of 20)

Table C3 (Continued)

	D_{CHP}/D_{BKF} Ratio										
Q_{BKF}	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3	3.1	3.2
6150	41390	45141	48892	52644	56395	60147	63898	67650	71401	75153	78904
6200	41726	45508	49290	53072	56854	60636	64418	68200	71982	75764	79546
6250	42063	45875	49687	53500	57312	61125	64937	68750	72562	76375	80187
6300	42399	46242	50085	53928	57771	61614	65457	69300	73143	76986	80829
6350	42736	46609	50482	54356	58229	62103	65976	69850	73723	77597	81470
6400	43072	46976	50880	54784	58688	62592	66496	70400	74304	78208	82112
6450	43409	47343	51277	55212	59146	63081	67015	70950	74884	78819	82753
6500	43745	47710	51675	55640	59605	63570	67535	71500	75465	79430	83395
6550	44082	48077	52072	56068	60063	64059	68054	72050	76045	80041	84036
6600	44418	48444	52470	56496	60522	64548	68574	72600	76626	80652	84678
6650	44755	48811	52867	56924	60980	65037	69093	73150	77206	81263	85319
6700	45091	49178	53265	57352	61439	65526	69613	73700	77787	81874	85961
6750	45428	49545	53662	57780	61897	66015	70132	74250	78367	82485	86602
6800	45764	49912	54060	58208	62356	66504	70652	74800	78948	83096	87244
6850	46101	50279	54457	58636	62814	66993	71171	75350	79528	83707	87885
6900	46437	50646	54855	59064	63273	67482	71691	75900	80109	84318	88527
6950	46774	51013	55252	59492	63731	67971	72210	76450	80689	84929	89168
7000	47110	51380	55650	59920	64190	68460	72730	77000	81270	85540	89810
7050	47447	51747	56047	60348	64648	68949	73249	77550	81850	86151	90451
7100	47783	52114	56445	60776	65107	69438	73769	78100	82431	86762	91093
7150	48120	52481	56842	61204	65565	69927	74288	78650	83011	87373	91734
7200	48456	52848	57240	61632	66024	70416	74808	79200	83592	87984	92376
7250	48793	53215	57637	62060	66482	70905	75327	79750	84172	88595	93017
7300	49129	53582	58035	62488	66941	71394	75847	80300	84753	89206	93659
7350	49466	53949	58432	62916	67399	71883	76366	80850	85333	89817	94300
7400	49802	54316	58830	63344	67858	72372	76886	81400	85914	90428	94942
7450	50139	54683	59227	63772	68316	72861	77405	81950	86494	91039	95583
7500	50475	55050	59625	64200	68775	73350	77925	82500	87075	91650	96225
7550	50812	55417	60022	64628	69233	73839	78444	83050	87655	92261	96866
7600	51148	55784	60420	65056	69692	74328	78964	83600	88236	92872	97508
7650	51485	56151	60817	65484	70150	74817	79483	84150	88816	93483	98149
7700	51821	56518	61215	65912	70609	75306	80003	84700	89397	94094	98791
7750	52158	56885	61612	66340	71067	75795	80522	85250	89977	94705	99432
7800	52494	57252	62010	66768	71526	76284	81042	85800	90558	95316	100074
7850	52831	57619	62407	67196	71984	76773	81561	86350	91138	95927	100715
7900	53167	57986	62805	67624	72443	77262	82081	86900	91719	96538	101357
7950	53503	58353	63202	68052	72901	77751	82600	87450	92299	97149	101998
8000	53840	58720	63600	68480	73360	78240	83120	88000	92880	97760	102640
8050	54176	59087	63997	68908	73818	78729	83639	88550	93460	98371	103281
8100	54513	59454	64395	69336	74277	79218	84159	89100	94041	98982	103923

(Sheet 9 of 20)

Table C3 (Continued)											
	D_{CHF}/D_{BKF} Ratio										
Q_{BKF}	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3	3.1	3.2
8150	54849	59821	64792	69764	74735	79707	84678	89650	94621	99593	104564
8200	55186	60188	65190	70192	75194	80196	85198	90200	95202	100204	105206
8250	55522	60555	65587	70620	75652	80685	85717	90750	95782	100815	105847
8300	55859	60922	65985	71048	76111	81174	86237	91300	96363	101426	106489
8350	56195	61289	66382	71476	76569	81663	86756	91850	96943	102037	107130
8400	56532	61656	66780	71904	77028	82152	87276	92400	97524	102648	107772
8450	56868	62023	67177	72332	77486	82641	87795	92950	98104	103259	108413
8500	57205	62390	67575	72760	77945	83130	88315	93500	98685	103870	109055
8550	57541	62757	67972	73188	78403	83619	88834	94050	99265	104481	109696
8600	57878	63124	68370	73616	78862	84108	89354	94600	99846	105092	110338
8650	58214	63491	68767	74044	79320	84597	89873	95150	100426	105703	110979
8700	58551	63858	69165	74472	79779	85086	90393	95700	101007	106314	111621
8750	58887	64225	69562	74900	80237	85575	90912	96250	101587	106925	112262
8800	59224	64592	69960	75328	80696	86064	91432	96800	102168	107536	112904
8850	59560	64959	70357	75756	81154	86553	91951	97350	102748	108147	113545
8900	59897	65326	70755	76184	81613	87042	92471	97900	103329	108758	114187
8950	60233	65693	71152	76612	82071	87531	92990	98450	103909	109369	114828
9000	60570	66060	71550	77040	82530	88020	93510	99000	104490	109980	115470
9050	60906	66427	71947	77468	82988	88509	94029	99550	105070	110591	116111
9100	61243	66794	72345	77896	83447	88998	94549	100100	105651	111202	116753
9150	61579	67161	72742	78324	83905	89487	95068	100650	106231	111813	117394
9200	61916	67528	73140	78752	84364	89976	95588	101200	106812	112424	118036
9250	62252	67895	73537	79180	84822	90465	96107	101750	107392	113035	118677
9300	62589	68262	73935	79608	85281	90954	96627	102300	107973	113646	119319
9350	62925	68629	74332	80036	85739	91443	97146	102850	108553	114257	119960
9400	63262	68996	74730	80464	86198	91932	97666	103400	109134	114868	120602
9450	63598	69363	75127	80892	86656	92421	98185	103950	109714	115479	121243
9500	63935	69730	75525	81320	87115	92910	98705	104500	110295	116090	121885
9550	64271	70097	75922	81748	87573	93399	99224	105050	110875	116701	122526
9600	64608	70464	76320	82176	88032	93888	99744	105600	111456	117312	123168
9650	64944	70831	76717	82604	88490	94377	100263	106150	112036	117923	123809
9700	65281	71198	77115	83032	88949	94866	100783	106700	112617	118534	124451
9750	65618	71565	77512	83460	89407	95355	101302	107250	113197	119145	125092
9800	65954	71932	77910	83888	89866	95844	101822	107800	113778	119756	125734
9850	66291	72299	78307	84316	90324	96333	102341	108350	114358	120367	126375
9900	66627	72666	78705	84744	90783	96822	102861	108900	114939	120978	127017
9950	66964	73033	79102	85172	91241	97311	103380	109450	115519	121589	127658
10000	67300	73400	79500	85600	91700	97800	103900	110000	116100	122200	128300
											(Sheet 10 of 20)

Table C3 (Continued)

	D_{CHF}/D_{BKF} Ratio										
Q_{BKF}	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4	4.1	4.2	4.3
50	672	702.5	733	763.5	794	824.5	855	885.5	916	946.5	977
100	1344	1405	1466	1527	1588	1649	1710	1771	1832	1893	1954
150	2016	2107.5	2199	2290.5	2382	2473.5	2565	2656.5	2748	2839.5	2931
200	2688	2810	2932	3054	3176	3298	3420	3542	3664	3786	3908
250	3360	3512.5	3665	3817.5	3970	4122.5	4275	4427.5	4580	4732.5	4885
300	4032	4215	4398	4581	4764	4947	5130	5313	5496	5679	5862
350	4704	4917.5	5131	5344.5	5558	5771.5	5985	6198.5	6412	6625.5	6839
400	5376	5620	5864	6108	6352	6596	6840	7084	7328	7572	7816
450	6048	6322.5	6597	6871.5	7146	7420.5	7695	7969.5	8244	8518.5	8793
500	6720	7025	7330	7635	7940	8245	8550	8855	9160	9465	9770
550	7392	7727.5	8063	8398.5	8734	9069.5	9405	9740.5	10076	10412	10747
600	8064	8430	8796	9162	9528	9894	10260	10626	10992	11358	11724
650	8736	9132.5	9529	9925.5	10322	10718	11115	11511	11908	12305	12701
700	9408	9835	10262	10689	11116	11543	11970	12397	12824	13251	13678
750	10080	10537	10995	11453	11910	12367	12825	13282	13740	14198	14655
800	10752	11240	11728	12216	12704	13192	13680	14168	14656	15144	15632
850	11424	11942	12461	12980	13498	14016	14535	15053	15572	16091	16609
900	12096	12645	13194	13743	14292	14841	15390	15939	16488	17037	17586
950	12768	13347	13927	14507	15086	15665	16245	16824	17404	17984	18563
1000	13440	14050	14660	15270	15880	16490	17100	17710	18320	18930	19540
1050	14112	14752	15393	16034	16674	17314	17955	18595	19236	19877	20517
1100	14784	15455	16126	16797	17468	18139	18810	19481	20152	20823	21494
1150	15456	16157	16859	17561	18262	18963	19665	20366	21068	21770	22471
1200	16128	16860	17592	18324	19056	19788	20520	21252	21984	22716	23448
1250	16800	17562	18325	19088	19850	20612	21375	22137	22900	23663	24425
1300	17472	18265	19058	19851	20644	21437	22230	23023	23816	24609	25402
1350	18144	18967	19791	20615	21438	22261	23085	23908	24732	25556	26379
1400	18816	19670	20524	21378	22232	23086	23940	24794	25648	26502	27356
1450	19488	20372	21257	22142	23026	23910	24795	25679	26564	27449	28333
1500	20160	21075	21990	22905	23820	24735	25650	26565	27480	28395	29310
1550	20832	21777	22723	23669	24614	25559	26505	27450	28396	29342	30287
1600	21504	22480	23456	24432	25408	26384	27360	28336	29312	30288	31264
1650	22176	23182	24189	25196	26202	27208	28215	29221	30228	31235	32241
1700	22848	23885	24922	25959	26996	28033	29070	30107	31144	32181	33218
1750	23520	24587	25655	26723	27790	28857	29925	30992	32060	33128	34195
1800	24192	25290	26388	27486	28584	29682	30780	31878	32976	34074	35172
1850	24864	25992	27121	28250	29378	30506	31635	32763	33892	35021	36149
1900	25536	26695	27854	29013	30172	31331	32490	33649	34808	35967	37126
1950	26208	27397	28587	29777	30966	32155	33345	34534	35724	36914	38103
2000	26880	28100	29320	30540	31760	32980	34200	35420	36640	37860	39080

(Sheet 11 of 20)

Table C3 (Continued)

	D_{CHF}/D_{BKF} Ratio										
Q_{BKF}	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4	4.1	4.2	4.3
2050	27552	28802	30053	31304	32554	33804	35055	36305	37556	38807	40057
2100	28224	29505	30786	32067	33348	34629	35910	37191	38472	39753	41034
2150	28896	30207	31519	32831	34142	35453	36765	38076	39388	40700	42011
2200	29568	30910	32252	33594	34936	36278	37620	38962	40304	41646	42988
2250	30240	31612	32985	34358	35730	37102	38475	39847	41220	42593	43965
2300	30912	32315	33718	35121	36524	37927	39330	40733	42136	43539	44942
2350	31584	33017	34451	35885	37318	38751	40185	41618	43052	44486	45919
2400	32256	33720	35184	36648	38112	39576	41040	42504	43968	45432	46896
2450	32928	34422	35917	37412	38906	40400	41895	43389	44884	46379	47873
2500	33600	35125	36650	38175	39700	41225	42750	44275	45800	47325	48850
2550	34272	35827	37383	38939	40494	42049	43605	45160	46716	48272	49827
2600	34944	36530	38116	39702	41288	42874	44460	46046	47632	49218	50804
2650	35616	37232	38849	40466	42082	43698	45315	46931	48548	50165	51781
2700	36288	37935	39582	41229	42876	44523	46170	47817	49464	51111	52758
2750	36960	38637	40315	41993	43670	45347	47025	48702	50380	52058	53735
2800	37632	39340	41048	42756	44464	46172	47880	49588	51296	53004	54712
2850	38304	40042	41781	43520	45258	46996	48735	50473	52212	53951	55689
2900	38976	40745	42514	44283	46052	47821	49590	51359	53128	54897	56666
2950	39648	41447	43247	45047	46846	48645	50445	52244	54044	55844	57643
3000	40320	42150	43980	45810	47640	49470	51300	53130	54960	56790	58620
3050	40992	42852	44713	46574	48434	50294	52155	54015	55876	57737	59597
3100	41664	43555	45446	47337	49228	51119	53010	54901	56792	58683	60574
3150	42336	44257	46179	48101	50022	51943	53865	55786	57708	59630	61551
3200	43008	44960	46912	48864	50816	52768	54720	56672	58624	60576	62528
3250	43680	45662	47645	49628	51610	53592	55575	57557	59540	61523	63505
3300	44352	46365	48378	50391	52404	54417	56430	58443	60456	62469	64482
3350	45024	47067	49111	51155	53198	55241	57285	59328	61372	63416	65459
3400	45696	47770	49844	51918	53992	56066	58140	60214	62288	64362	66436
3450	46368	48472	50577	52682	54786	56890	58995	61099	63204	65309	67413
3500	47040	49175	51310	53445	55580	57715	59850	61985	64120	66255	68390
3550	47712	49877	52043	54209	56374	58539	60705	62870	65036	67202	69367
3600	48384	50580	52776	54972	57168	59364	61560	63756	65952	68148	70344
3650	49056	51282	53509	55736	57962	60188	62415	64641	66868	69095	71321
3700	49728	51985	54242	56499	58756	61013	63270	65527	67784	70041	72298
3750	50400	52687	54975	57263	59550	61837	64125	66412	68700	70988	73275
3800	51072	53390	55708	58026	60344	62662	64980	67298	69616	71934	74252
3850	51744	54092	56441	58790	61138	63486	65835	68183	70532	72881	75229
3900	52416	54795	57174	59553	61932	64311	66690	69069	71448	73827	76206
3950	53088	55497	57907	60317	62726	65135	67545	69954	72364	74774	77183
4000	53760	56200	58640	61080	63520	65960	68400	70840	73280	75720	78160
4050	54432	56902	59373	61844	64314	66784	69255	71725	74196	76667	79137

(Sheet 12 of 20)

Table C3 (Continued)											
	D_{CHP}/D_{BKF} Ratio										
Q_{BKF}	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4	4.1	4.2	4.3
4100	55104	57605	60106	62607	65108	67609	70110	72611	75112	77613	80114
4150	55776	58307	60839	63371	65902	68433	70965	73496	76028	78560	81091
4200	56448	59010	61572	64134	66696	69258	71820	74382	76944	79506	82068
4250	57120	59712	62305	64898	67490	70082	72675	75267	77860	80453	83045
4300	57792	60415	63038	65661	68284	70907	73530	76153	78776	81399	84022
4350	58464	61117	63771	66425	69078	71731	74385	77038	79692	82346	84999
4400	59136	61820	64504	67188	69872	72556	75240	77924	80608	83292	85976
4450	59808	62522	65237	67952	70666	73380	76095	78809	81524	84239	86953
4500	60480	63225	65970	68715	71460	74205	76950	79695	82440	85185	87930
4550	61152	63927	66703	69479	72254	75029	77805	80580	83356	86132	88907
4600	61824	64630	67436	70242	73048	75854	78660	81466	84272	87078	89884
4650	62496	65332	68169	71006	73842	76678	79515	82351	85188	88025	90861
4700	63168	66035	68902	71769	74636	77503	80370	83237	86104	88971	91838
4750	63840	66737	69635	72533	75430	78327	81225	84122	87020	89918	92815
4800	64512	67440	70368	73296	76224	79152	82080	85008	87936	90864	93792
4850	65184	68142	71101	74060	77018	79976	82935	85893	88852	91811	94769
4900	65856	68845	71834	74823	77812	80801	83790	86779	89768	92757	95746
4950	66528	69547	72567	75587	78606	81625	84645	87664	90684	93704	96723
5000	67200	70250	73300	76350	79400	82450	85500	88550	91600	94650	97700
5050	67872	70952	74033	77114	80194	83274	86355	89435	92516	95597	98677
5100	68544	71655	74766	77877	80988	84099	87210	90321	93432	96543	99654
5150	69216	72357	75499	78641	81782	84923	88065	91206	94348	97490	100631
5200	69888	73060	76232	79404	82576	85748	88920	92092	95264	98436	101608
5250	70560	73762	76965	80168	83370	86572	89775	92977	96180	99383	102585
5300	71232	74465	77698	80931	84164	87397	90630	93863	97096	100329	103562
5350	71904	75167	78431	81695	84958	88221	91485	94748	98012	101276	104539
5400	72576	75870	79164	82458	85752	89046	92340	95634	98928	102222	105516
5450	73248	76572	79897	83222	86546	89870	93195	96519	99844	103169	106493
5500	73920	77275	80630	83985	87340	90695	94050	97405	100760	104115	107470
5550	74592	77977	81363	84749	88134	91519	94905	98290	101676	105062	108447
5600	75264	78680	82096	85512	88928	92344	95760	99176	102592	106008	109424
5650	75936	79382	82829	86276	89722	93168	96615	100061	103508	106955	110401
5700	76608	80085	83562	87039	90516	93993	97470	100947	104424	107901	111378
5750	77280	80787	84295	87803	91310	94817	98325	101832	105340	108848	112355
5800	77952	81490	85028	88566	92104	95642	99180	102718	106256	109794	113332
5850	78624	82192	85761	89330	92898	96466	100035	103603	107172	110741	114309
5900	79296	82895	86494	90093	93692	97291	100890	104489	108088	111687	115286
5950	79968	83597	87227	90857	94486	98115	101745	105374	109004	112634	116263
6000	80640	84300	87960	91620	95280	98940	102600	106260	109920	113580	117240
6050	81312	85002	88693	92384	96074	99764	103455	107145	110836	114527	118217
											(Sheet 13 of 20)

Table C3 (Continued)

	D_{CHP}/D_{BKF} Ratio										
Q_{BKF}	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4	4.1	4.2	4.3
6100	81984	85705	89426	93147	96868	100589	104310	108031	111752	115473	119194
6150	82656	86407	90159	93911	97662	101413	105165	108916	112668	116420	120171
6200	83328	87110	90892	94674	98456	102238	106020	109802	113584	117366	121148
6250	84000	87812	91625	95438	99250	103062	106875	110687	114500	118313	122125
6300	84672	88515	92358	96201	100044	103887	107730	111573	115416	119259	123102
6350	85344	89217	93091	96965	100838	104711	108585	112458	116332	120206	124079
6400	86016	89920	93824	97728	101632	105536	109440	113344	117248	121152	125056
6450	86688	90622	94557	98492	102426	106360	110295	114229	118164	122099	126033
6500	87360	91325	95290	99255	103220	107185	111150	115115	119080	123045	127010
6550	88032	92027	96023	100019	104014	108009	112005	116000	119996	123992	127987
6600	88704	92730	96756	100782	104808	108834	112860	116886	120912	124938	128964
6650	89376	93432	97489	101546	105602	109658	113715	117771	121828	125885	129941
6700	90048	94135	98222	102309	106396	110483	114570	118657	122744	126831	130918
6750	90720	94837	98955	103073	107190	111307	115425	119542	123660	127778	131895
6800	91392	95540	99688	103836	107984	112132	116280	120428	124576	128724	132872
6850	92064	96242	100421	104600	108778	112956	117135	121313	125492	129671	133849
6900	92736	96945	101154	105363	109572	113781	117990	122199	126408	130617	134826
6950	93408	97647	101887	106127	110366	114605	118845	123084	127324	131564	135803
7000	94080	98350	102620	106890	111160	115430	119700	123970	128240	132510	136780
7050	94752	99052	103353	107654	111954	116254	120555	124855	129156	133457	137757
7100	95424	99755	104086	108417	112748	117079	121410	125741	130072	134403	138734
7150	96096	100457	104819	109181	113542	117903	122265	126626	130988	135350	139711
7200	96768	101160	105552	109944	114336	118728	123120	127512	131904	136296	140688
7250	97440	101862	106285	110708	115130	119552	123975	128397	132820	137243	141665
7300	98112	102565	107018	111471	115924	120377	124830	129283	133736	138189	142642
7350	98784	103267	107751	112235	116718	121201	125685	130168	134652	139136	143619
7400	99456	103970	108484	112998	117512	122026	126540	131054	135568	140082	144596
7450	100128	104672	109217	113762	118306	122850	127395	131939	136484	141029	145573
7500	100800	105375	109950	114525	119100	123675	128250	132825	137400	141975	146550
7550	101472	106077	110683	115289	119894	124499	129105	133710	138316	142922	147527
7600	102144	106780	111416	116052	120688	125324	129960	134596	139232	143868	148504
7650	102816	107482	112149	116816	121482	126148	130815	135481	140148	144815	149481
7700	103488	108185	112882	117579	122276	126973	131670	136367	141064	145761	150458
7750	104160	108887	113615	118343	123070	127797	132525	137252	141980	146708	151435
7800	104832	109590	114348	119106	123864	128622	133380	138138	142896	147654	152412
7850	105504	110292	115081	119870	124658	129446	134235	139023	143812	148601	153389
7900	106176	110995	115814	120633	125452	130271	135090	139909	144728	149547	154366
7950	106848	111697	116547	121397	126246	131095	135945	140794	145644	150494	155343
8000	107520	112400	117280	122160	127040	131920	136800	141680	146560	151440	156320
8050	108192	113102	118013	122924	127834	132744	137655	142565	147476	152387	157297
8100	108864	113805	118746	123687	128628	133569	138510	143451	148392	153333	158274

(Sheet 14 of 20)

Table C3 (Continued)

	D_{CHP}/D_{BKF} Ratio										
Q_{BKF}	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4	4.1	4.2	4.3
8150	109536	114507	119479	124451	129422	134393	139365	144336	149308	154280	159251
8200	110208	115210	120212	125214	130216	135218	140220	145222	150224	155226	160228
8250	110880	115912	120945	125978	131010	136042	141075	146107	151140	156173	161205
8300	111552	116615	121678	126741	131804	136867	141930	146993	152056	157119	162182
8350	112224	117317	122411	127505	132598	137691	142785	147878	152972	158066	163159
8400	112896	118020	123144	128268	133392	138516	143640	148764	153888	159012	164136
8450	113568	118722	123877	129032	134186	139340	144495	149649	154804	159959	165113
8500	114240	119425	124610	129795	134980	140165	145350	150535	155720	160905	166090
8550	114912	120127	125343	130559	135774	140989	146205	151420	156636	161852	167067
8600	115584	120830	126076	131322	136568	141814	147060	152306	157552	162798	168044
8650	116256	121532	126809	132086	137362	142638	147915	153191	158468	163745	169021
8700	116928	122235	127542	132849	138156	143463	148770	154077	159384	164691	169998
8750	117600	122937	128275	133613	138950	144287	149625	154962	160300	165638	170975
8800	118272	123640	129008	134376	139744	145112	150480	155848	161216	166584	171952
8850	118944	124342	129741	135140	140538	145936	151335	156733	162132	167531	172929
8900	119616	125045	130474	135903	141332	146761	152190	157619	163048	168477	173906
8950	120288	125747	131207	136667	142126	147585	153045	158504	163964	169424	174883
9000	120960	126450	131940	137430	142920	148410	153900	159390	164880	170370	175860
9050	121632	127152	132673	138194	143714	149234	154755	160275	165796	171317	176837
9100	122304	127855	133406	138957	144508	150059	155610	161161	166712	172263	177814
9150	122976	128557	134139	139721	145302	150883	156465	162046	167628	173210	178791
9200	123648	129260	134872	140484	146096	151708	157320	162932	168544	174156	179768
9250	124320	129962	135605	141248	146890	152532	158175	163817	169460	175103	180745
9300	124992	130665	136338	142011	147684	153357	159030	164703	170376	176049	181722
9350	125664	131367	137071	142775	148478	154181	159885	165588	171292	176996	182699
9400	126336	132070	137804	143538	149272	155006	160740	166474	172208	177942	183676
9450	127008	132772	138537	144302	150066	155830	161595	167359	173124	178889	184653
9500	127680	133475	139270	145065	150860	156655	162450	168245	174040	179835	185630
9550	128352	134177	140003	145829	151654	157479	163305	169130	174956	180782	186607
9600	129024	134880	140736	146592	152448	158304	164160	170016	175872	181728	187584
9650	129696	135582	141469	147356	153242	159128	165015	170901	176788	182675	188561
9700	130368	136285	142202	148119	154036	159953	165870	171787	177704	183621	189538
9750	131040	136987	142935	148883	154830	160777	166725	172672	178620	184568	190515
9800	131712	137690	143668	149646	155624	161602	167580	173558	179536	185514	191492
9850	132384	138392	144401	150410	156418	162426	168435	174443	180452	186461	192469
9900	133056	139095	145134	151173	157212	163251	169290	175329	181368	187407	193446
9950	133728	139797	145867	151937	158006	164075	170145	176214	182284	188354	194423
10000	134400	140500	146600	152700	158800	164900	171000	177100	183200	189300	195400

(Sheet 15 of 20)

Table C3 (Continued)											
	D_{CHF}/D_{BKF} Ratio										
Q_{BKF}	4.4	4.5	4.6	4.7	4.8	4.9	5	5.1	5.2	5.3	5.4
50	1007.5	1038	1068.5	1099	1129.5	1160	1190.5	1221	1251.5	1282	1312.5
100	2015	2076	2137	2198	2259	2320	2381	2442	2503	2564	2625
150	3022.5	3114	3205.5	3297	3388.5	3480	3571.5	3663	3754.5	3846	3937.5
200	4030	4152	4274	4396	4518	4640	4762	4884	5006	5128	5250
250	5037.5	5190	5342.5	5495	5647.5	5800	5952.5	6105	6257.5	6410	6562.5
300	6045	6228	6411	6594	6777	6960	7143	7326	7509	7692	7875
350	7052.5	7266	7479.5	7693	7906.5	8120	8333.5	8547	8760.5	8974	9187.5
400	8060	8304	8548	8792	9036	9280	9524	9768	10012	10256	10500
450	9067.5	9342	9616.5	9891	10165	10440	10715	10989	11263	11538	11812
500	10075	10380	10685	10990	11295	11600	11905	12210	12515	12820	13125
550	11083	11418	11753	12089	12424	12760	13096	13431	13766	14102	14437
600	12090	12456	12822	13188	13554	13920	14286	14652	15018	15384	15750
650	13097	13494	13890	14287	14683	15080	15477	15873	16269	16666	17062
700	14105	14532	14959	15386	15813	16240	16667	17094	17521	17948	18375
750	15112	15570	16027	16485	16942	17400	17858	18315	18773	19230	19687
800	16120	16608	17096	17584	18072	18560	19048	19536	20024	20512	21000
850	17128	17646	18164	18683	19201	19720	20239	20757	21275	21794	22312
900	18135	18684	19233	19782	20331	20880	21429	21978	22527	23076	23625
950	19143	19722	20301	20881	21460	22040	22620	23199	23778	24358	24937
1000	20150	20760	21370	21980	22590	23200	23810	24420	25030	25640	26250
1050	21158	21798	22438	23079	23719	24360	25001	25641	26281	26922	27562
1100	22165	22836	23507	24178	24849	25520	26191	26862	27533	28204	28875
1150	23173	23874	24575	25277	25978	26680	27382	28083	28784	29486	30187
1200	24180	24912	25644	26376	27108	27840	28572	29304	30036	30768	31500
1250	25188	25950	26712	27475	28237	29000	29763	30525	31287	32050	32812
1300	26195	26988	27781	28574	29367	30160	30953	31746	32539	33332	34125
1350	27202	28026	28849	29673	30496	31320	32144	32967	33791	34614	35437
1400	28210	29064	29918	30772	31626	32480	33334	34188	35042	35896	36750
1450	29217	30102	30986	31871	32755	33640	34525	35409	36294	37178	38062
1500	30225	31140	32055	32970	33885	34800	35715	36630	37545	38460	39375
1550	31232	32178	33123	34069	35014	35960	36906	37851	38796	39742	40687
1600	32240	33216	34192	35168	36144	37120	38096	39072	40048	41024	42000
1650	33248	34254	35260	36267	37273	38280	39287	40293	41299	42306	43312
1700	34255	35292	36329	37366	38403	39440	40477	41514	42551	43588	44625
1750	35263	36330	37397	38465	39532	40600	41668	42735	43802	44870	45937
1800	36270	37368	38466	39564	40662	41760	42858	43956	45054	46152	47250
1850	37278	38406	39534	40663	41791	42920	44049	45177	46305	47434	48562
1900	38285	39444	40603	41762	42921	44080	45239	46398	47557	48716	49875
1950	39293	40482	41671	42861	44050	45240	46430	47619	48808	49998	51187
2000	40300	41520	42740	43960	45180	46400	47620	48840	50060	51280	52500
2050	41308	42558	43808	45059	46309	47560	48811	50061	51311	52562	53812
											(Sheet 16 of 20)

Table C3 (Continued)

	D_{CHF}/D_{BKF} Ratio										
Q_{BKF}	4.4	4.5	4.6	4.7	4.8	4.9	5	5.1	5.2	5.3	5.4
2100	42315	43596	44877	46158	47439	48720	50001	51282	52563	53844	55125
2150	43323	44634	45945	47257	48568	49880	51192	52503	53814	55126	56437
2200	44330	45672	47014	48356	49698	51040	52382	53724	55066	56408	57750
2250	45338	46710	48082	49455	50827	52200	53573	54945	56317	57690	59062
2300	46345	47748	49151	50554	51957	53360	54763	56166	57569	58972	60375
2350	47353	48786	50219	51653	53086	54520	55954	57387	58820	60254	61687
2400	48360	49824	51288	52752	54216	55680	57144	58608	60072	61536	63000
2450	49368	50862	52356	53851	55345	56840	58335	59829	61323	62818	64312
2500	50375	51900	53425	54950	56475	58000	59525	61050	62575	64100	65625
2550	51383	52938	54493	56049	57604	59160	60716	62271	63826	65382	66937
2600	52390	53976	55562	57148	58734	60320	61906	63492	65078	66664	68250
2650	53397	55014	56630	58247	59863	61480	63097	64713	66330	67946	69562
2700	54405	56052	57699	59346	60993	62640	64287	65934	67581	69228	70875
2750	55412	57090	58767	60445	62122	63800	65478	67155	68833	70510	72187
2800	56420	58128	59836	61544	63252	64960	66668	68376	70084	71792	73500
2850	57427	59166	60904	62643	64381	66120	67859	69597	71336	73074	74812
2900	58435	60204	61973	63742	65511	67280	69049	70818	72587	74356	76125
2950	59442	61242	63041	64841	66640	68440	70240	72039	73839	75638	77437
3000	60450	62280	64110	65940	67770	69600	71430	73260	75090	76920	78750
3050	61457	63318	65178	67039	68899	70760	72621	74481	76341	78202	80062
3100	62465	64356	66247	68138	70029	71920	73811	75702	77593	79484	81375
3150	63472	65394	67315	69237	71158	73080	75002	76923	78844	80766	82687
3200	64480	66432	68384	70336	72288	74240	76192	78144	80096	82048	84000
3250	65487	67470	69452	71435	73417	75400	77383	79365	81347	83330	85312
3300	66495	68508	70521	72534	74547	76560	78573	80586	82599	84612	86625
3350	67503	69546	71589	73633	75676	77720	79764	81807	83850	85894	87937
3400	68510	70584	72658	74732	76806	78880	80954	83028	85102	87176	89250
3450	69518	71622	73726	75831	77935	80040	82145	84249	86353	88458	90562
3500	70525	72660	74795	76930	79065	81200	83335	85470	87605	89740	91875
3550	71533	73698	75863	78029	80194	82360	84526	86691	88856	91022	93187
3600	72540	74736	76932	79128	81324	83520	85716	87912	90108	92304	94500
3650	73548	75774	78000	80227	82453	84680	86907	89133	91359	93586	95812
3700	74555	76812	79069	81326	83583	85840	88097	90354	92611	94868	97125
3750	75563	77850	80137	82425	84712	87000	89288	91575	93862	96150	98437
3800	76570	78888	81206	83524	85842	88160	90478	92796	95114	97432	99750
3850	77578	79926	82274	84623	86971	89320	91669	94017	96365	98714	101062
3900	78585	80964	83343	85722	88101	90480	92859	95238	97617	99996	102375
3950	79593	82002	84411	86821	89230	91640	94050	96459	98868	101278	103687
4000	80600	83040	85480	87920	90360	92800	95240	97680	100120	102560	105000
4050	81608	84078	86548	89019	91489	93960	96431	98901	101371	103842	106312

(Sheet 17 of 20)

Table C3 (Continued)

	D_{CHP}/D_{BKF} Ratio										
Q_{BKF}	4.4	4.5	4.6	4.7	4.8	4.9	5	5.1	5.2	5.3	5.4
4100	82615	85116	87617	90118	92619	95120	97621	100122	102623	105124	107625
4150	83623	86154	88685	91217	93748	96280	98812	101343	103874	106406	108937
4200	84630	87192	89754	92316	94878	97440	100002	102564	105126	107688	110250
4250	85638	88230	90822	93415	96007	98600	101193	103785	106377	108970	111562
4300	86645	89268	91891	94514	97137	99760	102383	105006	107629	110252	112875
4350	87653	90306	92959	95613	98266	100920	103574	106227	108880	111534	114187
4400	88660	91344	94028	96712	99396	102080	104764	107448	110132	112816	115500
4450	89668	92382	95096	97811	100525	103240	105955	108669	111383	114098	116812
4500	90675	93420	96165	98910	101655	104400	107145	109890	112635	115380	118125
4550	91683	94458	97233	100009	102784	105560	108336	111111	113886	116662	119437
4600	92690	95496	98302	101108	103914	106720	109526	112332	115138	117944	120750
4650	93698	96534	99370	102207	105043	107880	110717	113553	116389	119226	122062
4700	94705	97572	100439	103306	106173	109040	111907	114774	117641	120508	123375
4750	95713	98610	101507	104405	107302	110200	113098	115995	118892	121790	124687
4800	96720	99648	102576	105504	108432	111360	114288	117216	120144	123072	126000
4850	97728	100686	103644	106603	109561	112520	115479	118437	121395	124354	127312
4900	98735	101724	104713	107702	110691	113680	116669	119658	122647	125636	128625
4950	99743	102762	105781	108801	111820	114840	117860	120879	123898	126918	129937
5000	100750	103800	106850	109900	112950	116000	119050	122100	125150	128200	131250
5050	101758	104838	107918	110999	114079	117160	120241	123321	126401	129482	132562
5100	102765	105876	108987	112098	115209	118320	121431	124542	127653	130764	133875
5150	103772	106914	110055	113197	116338	119480	122622	125763	128904	132046	135187
5200	104780	107952	111124	114296	117468	120640	123812	126984	130156	133328	136500
5250	105787	108990	112192	115395	118597	121800	125003	128205	131408	134610	137812
5300	106795	110028	113261	116494	119727	122960	126193	129426	132659	135892	139125
5350	107802	111066	114329	117593	120856	124120	127384	130647	133911	137174	140437
5400	108810	112104	115398	118692	121986	125280	128574	131868	135162	138456	141750
5450	109817	113142	116466	119791	123115	126440	129765	133089	136414	139738	143062
5500	110825	114180	117535	120890	124245	127600	130955	134310	137665	141020	144375
5550	111832	115218	118603	121989	125374	128760	132146	135531	138917	142302	145687
5600	112840	116256	119672	123088	126504	129920	133336	136752	140168	143584	147000
5650	113847	117294	120740	124187	127633	131080	134527	137973	141420	144866	148312
5700	114855	118332	121809	125286	128763	132240	135717	139194	142671	146148	149625
5750	115862	119370	122877	126385	129892	133400	136908	140415	143923	147430	150937
5800	116870	120408	123946	127484	131022	134560	138098	141636	145174	148712	152250
5850	117877	121446	125014	128583	132151	135720	139289	142857	146426	149994	153562
5900	118885	122484	126083	129682	133281	136880	140479	144078	147677	151276	154875
5950	119892	123522	127151	130781	134410	138040	141670	145299	148929	152558	156187
6000	120900	124560	128220	131880	135540	139200	142860	146520	150180	153840	157500
6050	121907	125598	129288	132979	136669	140360	144051	147741	151431	155122	158812
6100	122915	126636	130357	134078	137799	141520	145241	148962	152683	156404	160125

(Sheet 18 of 20)

Table C3 (Continued)

	D_{CHP}/D_{BKF} Ratio										
Q_{BKF}	4.4	4.5	4.6	4.7	4.8	4.9	5	5.1	5.2	5.3	5.4
6150	123922	127674	131425	135177	138928	142680	146432	150183	153934	157686	161437
6200	124930	128712	132494	136276	140058	143840	147622	151404	155186	158968	162750
6250	125937	129750	133562	137375	141187	145000	148813	152625	156437	160250	164062
6300	126945	130788	134631	138474	142317	146160	150003	153846	157689	161532	165375
6350	127952	131826	135699	139573	143446	147320	151194	155067	158940	162814	166687
6400	128960	132864	136768	140672	144576	148480	152384	156288	160192	164096	168000
6450	129967	133902	137836	141771	145705	149640	153575	157509	161443	165378	169312
6500	130975	134940	138905	142870	146835	150800	154765	158730	162695	166660	170625
6550	131983	135978	139973	143969	147964	151960	155956	159951	163946	167942	171937
6600	132990	137016	141042	145068	149094	153120	157146	161172	165198	169224	173250
6650	133998	138054	142110	146167	150223	154280	158337	162393	166449	170506	174562
6700	135005	139092	143179	147266	151353	155440	159527	163614	167701	171788	175875
6750	136013	140130	144247	148365	152482	156600	160718	164835	168952	173070	177187
6800	137020	141168	145316	149464	153612	157760	161908	166056	170204	174352	178500
6850	138028	142206	146384	150563	154741	158920	163099	167277	171455	175634	179812
6900	139035	143244	147453	151662	155871	160080	164289	168498	172707	176916	181125
6950	140043	144282	148521	152761	157000	161240	165480	169719	173958	178198	182437
7000	141050	145320	149590	153860	158130	162400	166670	170940	175210	179480	183750
7050	142058	146358	150658	154959	159259	163560	167861	172161	176461	180762	185062
7100	143065	147396	151727	156058	160389	164720	169051	173382	177713	182044	186375
7150	144073	148434	152795	157157	161518	165880	170242	174603	178964	183326	187687
7200	145080	149472	153864	158256	162648	167040	171432	175824	180216	184608	189000
7250	146088	150510	154932	159355	163777	168200	172623	177045	181467	185890	190312
7300	147095	151548	156001	160454	164907	169360	173813	178266	182719	187172	191625
7350	148103	152586	157069	161553	166036	170520	175004	179487	183970	188454	192937
7400	149110	153624	158138	162652	167166	171680	176194	180708	185222	189736	194250
7450	150118	154662	159206	163751	168295	172840	177385	181929	186473	191018	195562
7500	151125	155700	160275	164850	169425	174000	178575	183150	187725	192300	196875
7550	152133	156738	161343	165949	170554	175160	179766	184371	188976	193582	198187
7600	153140	157776	162412	167048	171684	176320	180956	185592	190228	194864	199500
7650	154148	158814	163480	168147	172813	177480	182147	186813	191479	196146	200812
7700	155155	159852	164549	169246	173943	178640	183337	188034	192731	197428	202125
7750	156163	160890	165617	170345	175072	179800	184528	189255	193982	198710	203437
7800	157170	161928	166686	171444	176202	180960	185718	190476	195234	199992	204750
7850	158178	162966	167754	172543	177331	182120	186909	191697	196485	201274	206062
7900	159185	164004	168823	173642	178461	183280	188099	192918	197737	202556	207375
7950	160193	165042	169891	174741	179590	184440	189290	194139	198988	203838	208687
8000	161200	166080	170960	175840	180720	185600	190480	195360	200240	205120	210000
8050	162208	167118	172028	176939	181849	186760	191671	196581	201491	206402	211312
8100	163215	168156	173097	178038	182979	187920	192861	197802	202743	207684	212625

(Sheet 19 of 20)

Table C3 (Concluded)

	D_{CHF}/D_{BKF} Ratio										
Q_{BKF}	4.4	4.5	4.6	4.7	4.8	4.9	5	5.1	5.2	5.3	5.4
8150	164223	169194	174165	179137	184108	189080	194052	199023	203994	208966	213937
8200	165230	170232	175234	180236	185238	190240	195242	200244	205246	210248	215250
8250	166238	171270	176302	181335	186367	191400	196433	201465	206497	211530	216562
8300	167245	172308	177371	182434	187497	192560	197623	202686	207749	212812	217875
8350	168253	173346	178439	183533	188626	193720	198814	203907	209000	214094	219187
8400	169260	174384	179508	184632	189756	194880	200004	205128	210252	215376	220500
8450	170268	175422	180576	185731	190885	196040	201195	206349	211503	216658	221812
8500	171275	176460	181645	186830	192015	197200	202385	207570	212755	217940	223125
8550	172283	177498	182713	187929	193144	198360	203576	208791	214006	219222	224437
8600	173290	178536	183782	189028	194274	199520	204766	210012	215258	220504	225750
8650	174298	179574	184850	190127	195403	200680	205957	211233	216509	221786	227062
8700	175305	180612	185919	191226	196533	201840	207147	212454	217761	223068	228375
8750	176313	181650	186987	192325	197662	203000	208338	213675	219012	224350	229687
8800	177320	182688	188056	193424	198792	204160	209528	214896	220264	225632	231000
8850	178328	183726	189124	194523	199921	205320	210719	216117	221515	226914	232312
8900	179335	184764	190193	195622	201051	206480	211909	217338	222767	228196	233625
8950	180343	185802	191261	196721	202180	207640	213100	218559	224018	229478	234937
9000	181350	186840	192330	197820	203310	208800	214290	219780	225270	230760	236250
9050	182358	187878	193398	198919	204439	209960	215481	221001	226521	232042	237562
9100	183365	188916	194467	200018	205569	211120	216671	222222	227773	233324	238875
9150	184373	189954	195535	201117	206698	212280	217862	223443	229024	234606	240187
9200	185380	190992	196604	202216	207828	213440	219052	224664	230276	235888	241500
9250	186388	192030	197672	203315	208957	214600	220243	225885	231527	237170	242812
9300	187395	193068	198741	204414	210087	215760	221433	227106	232779	238452	244125
9350	188403	194106	199809	205513	211216	216920	222624	228327	234030	239734	245437
9400	189410	195144	200878	206612	212346	218080	223814	229548	235282	241016	246750
9450	190418	196182	201946	207711	213475	219240	225005	230769	236533	242298	248062
9500	191425	197220	203015	208810	214605	220400	226195	231990	237785	243580	249375
9550	192433	198258	204083	209909	215734	221560	227386	233211	239036	244862	250687
9600	193440	199296	205152	211008	216864	222720	228576	234432	240288	246144	252000
9650	194448	200334	206220	212107	217993	223880	229767	235653	241539	247426	253312
9700	195455	201372	207289	213206	219123	225040	230957	236874	242791	248708	254625
9750	196463	202410	208357	214305	220252	226200	232148	238095	244042	249990	255937
9800	197470	203448	209426	215404	221382	227360	233338	239316	245294	251272	257250
9850	198478	204486	210494	216503	222511	228520	234529	240537	246545	252554	258562
9900	199485	205524	211563	217602	223641	229680	235719	241758	247797	253836	259875
9950	200493	206562	212631	218701	224770	230840	236910	242979	249048	255118	261187
10000	201500	207600	213700	219800	225900	232000	238100	244200	250300	256400	262500

(Sheet 20 of 20)

$$Q_{CHF} = [(-6.69 + 6.1 \times (D_{CHF} / D_{BKF})) \times Q_{BKF}] \quad \text{(C5)}$$

These values of Q_{BKF} and D_{CHF}/D_{BKF} ratio can be entered into Table C3 with the D_{CHF}/D_{BKF} ratio being listed horizontally across the top of the table and Q_{BKF} being listed vertically down the left side of the table. Where the columns for the two corresponding values intersect is the channel-full discharge.

Step 5. The fifth step is to use the value of Q_{CHF} and compare it with the values calculated in Tables C4 and C5. The values in these tables were generated using regression equations from the USGS National Flood Frequency program (Choquette 1988). If the value of channel-full flow (Q_{CHF}) is less than the flow given in the column headed Q_2, then it is assumed that the flow which occurs at least once every 2 years (the annual event) inundates the wetland. In other words, Q_{CHF} represents the amount of water which overflows the streambanks and inundates the wetland surface; therefore, if the flow which occurs annually (Q_2) is greater than this amount then the wetland floods annually. Further, if Q_{CHF}, is greater than the value given in column Q_2 but less than the value in Q_5 then the wetland is considered to have a recurrence interval of 5 years.

In summary, the steps involved in determining flood frequency using the regional dimensionless rating curve are:

a. Determine drainage area of adjacent stream above the wetland assessment area.

b. Determine average channel-full depth (D_{CHF}) in the field using a tape at a bridge crossing.

c. Determine average bankfull depth (D_{BKF}) from the bankfull depth versus drainage area relationship in Figure C7 or by solving the equation: $D_{BKF} = 0.49 \times (\text{drainage area}^{0.53})$.

d. Determine bankfull flow (Q_{BKF}) from the bankfull flow versus drainage area relationship in Figure C8 or by solving the equation: $Q_{BKF} = 1.46 \times (\text{drainage area}^{1.34})$.

e. Determine the value of the ratio of D_{CHF} / D_{BKF} (steps b and c) and enter the value and the value of Q_{BKF} (step d) into Table C3 to determine Q_{CHF}.

f. Determine from Figure C9 in which hydrologic region the wetland assessment area is located.

g. Compare the value of Q_{CHF} to the flows of different recurrence intervals in Tables C4 and C5. If Q_{CHF} is less than the corresponding value of Q_2, then the site floods annually. If Q_{CHF} is greater than Q_2 but less than Q_5 then the recurrence interval is estimated to 5 years (i.e., the wetland floods, on average, once every 5 years). If Q_{CHF} is greater than Q_5 but less than Q_{10} then the recurrence interval is estimated to be 10 years and so on.

Table C4
Flood Flows for the 2, 5, 10, and 25 Year Return Intervals for Hydrologic Region 6

	Return Interval Flows			
Drainage Area, mi^2	Q2	Q5	Q10	Q25
25.0	1417.6	2002.1	2358.4	2811.7
50.0	2504.4	3581.4	4251.1	5121.0
75.0	3493.6	5032.6	6000.4	7272.4
100.0	4424.4	6406.4	7662.6	9327.2
125.0	5313.9	7725.4	9263.0	11313.0
150.0	6172.0	9002.3	10815.7	13245.5
175.0	7004.6	10245.3	12329.9	15134.8
200.0	7816.2	11459.8	13811.9	16987.9
225.0	8609.8	12650.1	15266.2	18809.9
250.0	9387.7	13819.3	16696.5	20604.8
275.0	10151.8	14969.7	18105.4	22375.5
300.0	10903.6	16103.4	19495.3	24124.6
325.0	11644.2	17222.0	20867.8	25854.1
350.0	12374.6	18326.8	22224.6	27565.7
375.0	13095.8	19419.0	23566.9	29260.8
400.0	13808.4	20499.5	24895.9	30940.8
425.0	14513.1	21569.1	26212.4	32606.6
450.0	15210.4	22628.7	27517.4	34259.3
475.0	15900.7	23678.8	28811.5	35899.6
500.0	16584.6	24720.1	30095.5	37528.3
525.0	17262.5	25753.0	31369.8	39146.0
550.0	17934.5	26778.0	32635.1	40753.3
575.0	18601.1	27795.6	33891.8	42350.9
600.0	19262.6	28806.0	35140.3	43939.0
625.0	19919.1	29809.7	36381.0	45518.3
650.0	20570.9	30806.9	37614.3	47089.0
675.0	21218.3	31798.0	38840.5	48651.6
700.0	21861.4	32783.2	40059.9	50206.4
725.0	22500.4	33762.7	41272.8	51753.8
750.0	23135.4	34736.9	42479.4	53293.9
775.0	23766.7	35705.8	43680.0	54827.1
800.0	24394.3	36669.6	44874.8	56353.7
825.0	25018.5	37628.7	46064.1	57873.8
850.0	25639.2	38583.1	47247.9	59387.7
875.0	26256.7	39532.9	48426.5	60895.7
900.0	26871.1	40478.4	49600.1	62397.8
925.0	27482.4	41419.7	50768.8	63894.3
950.0	28090.7	42356.9	51932.8	65385.3
975.0	28696.2	43290.1	53092.1	66871.1
1000.0	29298.9	44219.5	54247.1	68351.7

Note: Average value for channel slope (5.4 used).
$Q_2 = 55 \times (\text{Drainage Area}^{0.821}) \times (5.4^{0.368})$.
$Q_5 = 66 \times (\text{Drainage Area}^{0.839}) \times (5.4^{0.422})$.
$Q_{10} = 71 \times (\text{Drainage Area}^{0.85}) \times (5.4^{0.454})$.
$Q_{25} = 75.5 \times (\text{Drainage Area}^{0.865}) \times (5.4^{0.494})$.

Table C5
Flood Flows for the 2, 5, 10, and 25 Year Return Intervals for Hydrologic Region 7

	Return Interval Flows			
Drainage Area, mi^2	Q2	Q5	Q10	Q25
25.0	1764.3	2862.9	3687.3	4853.7
50.0	2785.8	4483.1	5754.0	7563.7
75.0	3639.1	5827.9	7464.8	9804.7
100.0	4398.8	7020.1	8979.1	11786.8
125.0	5095.6	8110.5	10362.1	13596.2
150.0	5746.1	9125.9	11648.8	15278.9
175.0	6360.5	10083.0	12860.6	16863.2
200.0	6945.6	10992.9	14011.8	18367.7
225.0	7506.2	11863.3	15112.4	19805.8
250.0	8045.9	12700.2	16170.0	21187.3
275.0	8567.5	13508.1	17190.3	22520.0
300.0	9073.1	14290.3	18177.9	23809.6
325.0	9564.5	15049.9	19136.4	25061.1
350.0	10043.2	15789.1	20068.9	26278.4
375.0	10510.4	16509.8	20977.8	27464.7
400.0	10967.1	17213.8	21865.2	28622.9
425.0	11414.1	17902.4	22733.0	29755.3
450.0	11852.2	18576.9	23582.7	30863.9
475.0	12282.1	19238.2	24415.7	31950.6
500.0	12704.4	19887.4	25233.1	33016.8
525.0	13119.5	20525.2	26036.0	34064.1
550.0	13527.9	21152.4	26825.3	35093.5
575.0	13930.1	21769.6	27601.9	36106.2
600.0	14326.3	22377.3	28366.4	37103.2
625.0	14716.9	22976.2	29119.7	38085.4
650.0	15102.3	23566.7	29862.2	39053.4
675.0	15482.6	24149.3	30594.6	40008.2
700.0	15858.1	24724.2	31317.3	40950.3
725.0	16229.1	25292.0	32030.9	41880.4
750.0	16595.8	25852.9	32735.6	42799.0
775.0	16958.3	26407.2	33432.1	43706.7
800.0	17316.8	26955.3	34120.5	44603.9
825.0	17671.6	27497.3	34801.3	45491.0
850.0	18022.7	28033.6	35474.7	46368.5
875.0	18370.3	28564.3	36141.1	47236.7
900.0	18714.5	29089.7	36800.6	48096.1
925.0	19055.5	29610.0	37453.7	48946.9
950.0	19393.3	30125.3	38100.5	49789.5
975.0	19728.2	30635.9	38741.2	50624.2
1000.0	20060.1	31141.9	39376.0	51451.1

Note: Average values for basin shape (2.6) and sinuosity (1.8) used.
$Q_2 = 642 \times (\text{Drainage Area}^{0.659}) \times (2.6^{-0.569}) \times (1.8^{-0.964})$.
$Q_5 = 946 \times (\text{Drainage Area}^{0.647}) \times (2.6^{-0.523}) \times (1.8^{-0.809})$.
$Q_{10} = 1154 \times (\text{Drainage Area}^{0.642}) \times (2.6^{-0.501}) \times (1.8^{-0.725})$.
$Q_{25} = 1424 \times (\text{Drainage Area}^{0.64}) \times (2.6^{-0.482}) \times (1.8^{-0.635})$.

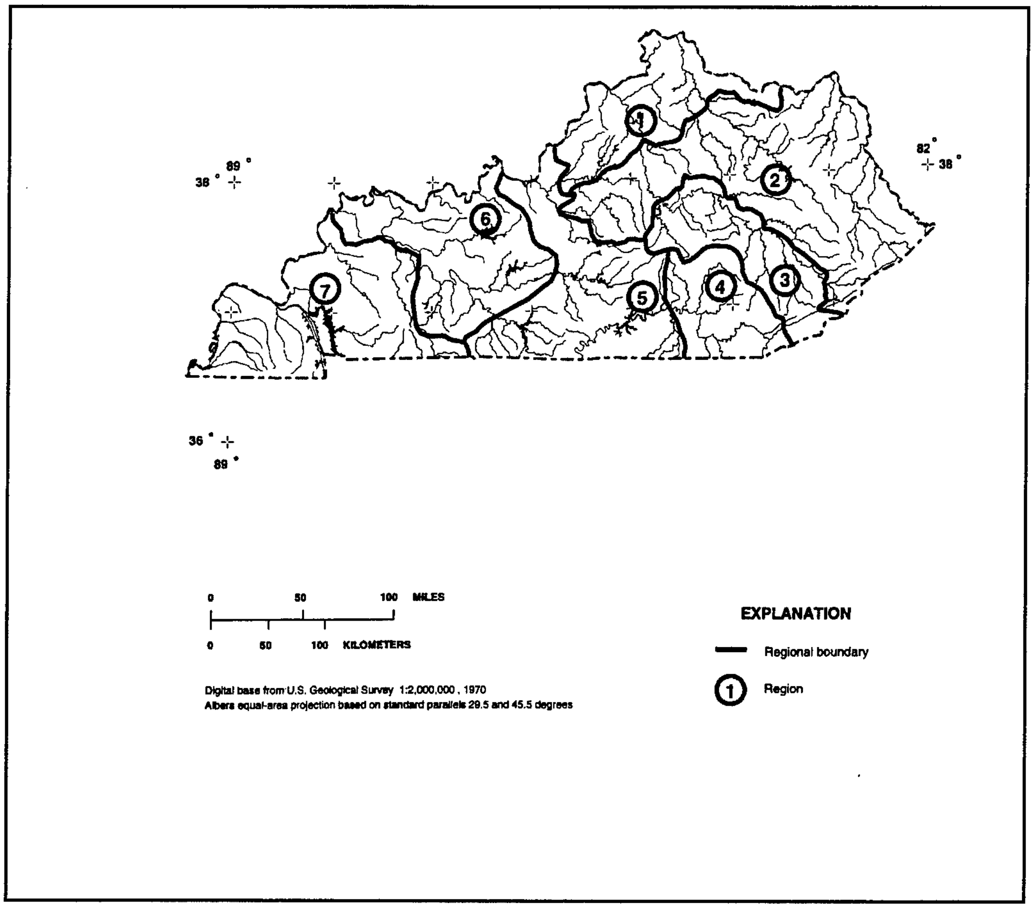


Figure C9. Flood-frequency region map for Kentucky

Appendix D
Reference Wetland Data

Table D1 contains the data collected at reference wetland sites in western Kentucky.

Table D1. Western Kentucky Low Gradient Riverine Wetland Reference Data Summary (129 Plots and 27 Variables)

Site-Plot Name	Stand Age	Description	1	2	3	4	5	6
		Variable Name ---->	*Vtract*	*Vcore*	*Vconnect*	*Vslope*	*Vstore*	*Vmacro*
		Metric ---->	size of wetland area	% of Vtract with >300m buffer	% of Vtract perimeter connected	% floodplain slope	Ratio of floodplain width to channel width	% of WAA with macro topography
		Units ---->	ha					
PC-PC	0	agricultural field, leveed	0	0	0	0.20	43	10
TW-PC	0	agricultural field, leveed	0	0	35	0.20	20	5
RR-PC1,PC2	0	agricultural field, ditched	0	0	10	0.30	81	5
Elkcrk1	0	ag field- proposed mitig/ditched	0	0	0	0.05	100	0
PRFW1-1,2,3	0	agricultural field, land levelled	0	0	25	0.30	155	0
PRFW2-1,2,3	0	agricultural field, land levelled	0	0	25	0.30	155	0
PRFW3-1,2,3	0	agricultural field, land levelled	0	0	25	0.30	155	0
Rold Ag 1-5	0	agricultural field-different soils	0	0	0	0.20	64	25
PRA-1,2	0-5	hammered, reclaim, compacted	3210	56	85	0.05	70	5
ERMit1-1,2,3	2	mitigation site	1117	50	37	0.13	56	15
NCMit1-1,2,3	5	BLH Mitigation -drier end of site	665	36	10	0.05	80	5
NCMit2-1,2,3	5	BLH Mitigation -wetter end of site	665	36	10	0.05	80	5
RC1-1,2,3	1-5	early successional, channelized	4800	20	25	0.05	40	0
RC2-1,2,3	1-5	early successional, channelized	4800	20	25	0.16	40	0
RC3-1,2,3	1-5	early successional, channelized	4800	20	25	0.22	40	0
CCMit 1,2,3	5	mitigation site	4848	20	20	0.05	10	0
ERMit2-1,2,3	10	mitigation site	1117	50	37	0.21	56	15
OHCo 1,2	10	abandonded prior converted	290	20	15	0.30	85	5
Mudcr1-1,2	5-10	early succession-channelized &leveed	2	0	50	0.05	18	0
Rold1-1,2	unknown	BLH selective cut - 1998	710	19	10	0.20	64	50
Mudcr2-1,2,3	10-15	Selective cut- wetter due to road	283	7	60	0.05	18	0
Mudcr3-1,2,3	15-20	BLH -drier due to road	6	7	60	0.05	18	0
McCln1-1,2,3,4	20-25	selectively cut 10 ya	135	14	10	1	39	0
PoC1,2,3	20-25	mined watershed, channelized, sediment	2673	35	10	0.08	20	20
IC-1,2,3	20-25	nuked, sediment, acid, beaver	380	0	0	0.05	32	20
EC1-1,2,3	20	channelized	6	0	0	0.11	60	0
EC2-1,2,3	20	channelized	6	0	0	0.23	60	0
EC3-1,2,3	20	channelized	6	0	0	0.23	60	0
Hanson1-1,2,3	25-30	selective cut	90	0	0	0.05	33	0
Rold2-1,2,3	25-30	selective cut	710	19	10	0.20	64	50
JC-1,2	30-40	channelized, high graded	1117	50	37	0.05	360	20
DC2-1,2	30-40	wetter, open canopy	3210	56	85	0.05	180	20
PR2-1,2	30-40	site scale standard, landscape altered	92	10	25	0.05	8	10
PR3-1,2,3,4,5,6	30-40	site scale standard, landscape altered	93	10	25	0.05	68	0
Mitproinc1-1,2,3	30-40	site scale standard, landscape altered	13	0	0	0.05	64	0
TC-1,2,3	30-40	channelized/ditched	340	5	30	0.04	10	40
WC-1,2,3	30-40	deep organic layer	3210	56	85	0.04	70	5
CC1-3	40+	reference standard	4848	20	20	0.03	70	5
CC2-1,2,3	40+	reference standard	4848	20	20	0.03	70	15
CC3-1,2,3	40+	reference standard	4800	20	75	0.03	56	15
DC1-1,2,3	40+	reference standard	3210	56	85	0.03	120	20
DC3-1,2,3	40+	reference standard	3210	56	85	0.03	216	20
DC4-1,2,3	40+	reference standard	3210	56	85	0.03	216	20
DC5-1,2,3	40+	reference standard	3210	56	85	0.03	216	20
PR-1,2,3	40+	reference standard	3210	56	85	0.05	70	5
Reference Stand Summary								
Mean			**1065**	**21**	**24**	**0.15**	**70**	**9**
Standard Error			267	3	4	0.02	11	2
Standard Deviation			1623	22	25	0.11	65	14
Minimum			**0**	**0**	**0**	**0.04**	**8**	**0**
Maximum			**4848**	**56**	**85**	**0.50**	**360**	**50**
Reference Standard Stand Summary								
Mean			**3818**	**43**	**68**	**0.03**	**129**	**15**
Standard Error			297	7	10	0.00	26	2
Standard Deviation			840	19	30	0.01	74	7
Minimum			**3210**	**20**	**20**	**0.03**	**56**	**5**
Maximum			**4848**	**56**	**85**	**0.05**	**216**	**20**

Table D1. continued

Site-Plot Name	Stand Age	Description	7	8	9	10	11	12
		Variable Name ---->	*Vfreq*	*Vrough*	*Vsoilint*	*Vwtf*	*Vwtd*	*Vwtslope*
		Metric ---->	reccurence interval	Manning's Roughness Coefficient *n*	% WAA altered	Water table fluctuations present (1) absent (0)	Depth to seasonal high water table	% WAA with altered water table
		Units ---->	years				inches	
PC-PC	0	agricultural field, leveed	1.5	0.04	0	1	0	100
TW-PC	0	agricultural field, leveed	1.5	0.04	0	1	6	0
RR-PC1,PC2	0	agricultural field, ditched	1.5	0.04	0	1	0	50
Elkcrk1	0	ag field- proposed mitig/ditched	1.0	0.04	0	1	7	50
PRFW1-1,2,3	0	agricultural field, land levelled	1.0	0.04	0	1	0	0
PRFW2-1,2,3	0	agricultural field, land levelled	1.0	0.04	0	1	0	0
PRFW3-1,2,3	0	agricultural field, land levelled	1.0	0.04	0	1	0	0
Rold Ag 1-5	0	agricultural field-different soils	1.0	0.04	0	1	5	0
PRA-1,2	0-5	hammered, reclaim, compacted	2.0	0.04	100	1	12	0
ERMit1-1,2,3	2	mitigation site	1.0	0.05	0	1	4	0
NCMit1-1,2,3	5	BLH Mitigation -drier end of site	1.0	0.05	0	1	6	0
NCMit2-1,2,3	5	BLH Mitigation -wetter end of site	1.0	0.05	0	1	6	0
RC1-1,2,3	1-5	early successional, channelized	1.0	0.06	0	1	9	100
RC2-1,2,3	1-5	early successional, channelized	1.0	0.06	0	1	9	100
RC3-1,2,3	1-5	early successional, channelized	1.0	0.06	0	1	9	100
CCMit 1,2,3	5	mitigation site	2.0	0.05	0	1	10	100
ERMit2-1,2,3	10	mitigation site	1.0	0.08	0	1	10	0
OHCo 1,2	10	abandonded prior converted	1.0	0.08	0	1	4	0
Mudcr1-1,2	5-10	early succession-channelized &leveed	5.0	0.09	0	1	9	100
Rold1-1,2	unknown	BLH selective cut - 1998	1.0	0.08	0	1	3	0
Mudcr2-1,2,3	10-15	Selective cut- wetter due to road	5.0	0.13	0	1	8	0
Mudcr3-1,2,3	15-20	BLH -drier due to road	5.0	0.12	0	1	9	50
McCln1-1,2,3,4	20-25	selectively cut 10 ya	1	0.18	0	1	1.5	0
PoC1,2,3	20-25	mined watershed, channelized, sediment	11.0	0.13	0	1	6	0
IC-1,2,3	20-25	nuked, sediment, acid, beaver	100.0	0.13	100	1	5	0
EC1-1,2,3	20	channelized	5.0	0.13	0	1	9	100
EC2-1,2,3	20	channelized	5.0	0.17	0	1	10	100
EC3-1,2,3	20	channelized	5.0	0.17	0	1	10	100
Hanson1-1,2,3	25-30	selective cut	1.0	0.12	0	1	6	0
Rold2-1,2,3	25-30	selective cut	1.0	0.12	0	1	3	0
JC-1,2	30-40	channelized, high graded	5.0	0.20	0	1	12	0
DC2-1,2	30-40	wetter, open canopy	1.0	0.12	0	1	6	100
PR2-1,2	30-40	site scale standard, landscape altered	1.0	0.12	0	1	18	0
PR3-1,2,3,4,5,6	30-40	site scale standard, landscape altered	1	0.12	0	1	0	0
Mitproinc1-1,2,3	30-40	site scale standard, landscape altered	1.0	0.12	0	1	6	0
TC-1,2,3	30-40	channelized/ditched	2.0	0.12	0	1	10	0
WC-1,2,3	30-40	deep organic layer	2.0	0.14	0	1	0	100
CC1-3	40+	reference standard	1.0	0.12	0	1	0	0
CC2-1,2,3	40+	reference standard	1.0	0.11	0	1	0	0
CC3-1,2,3	40+	reference standard	1.0	0.13	0	1	4	0
DC1-1,2,3	40+	reference standard	1.0	0.12	0	1	6	0
DC3-1,2,3	40+	reference standard	1.0	0.12	0	1	6	0
DC4-1,2,3	40+	reference standard	1.0	0.12	0	1	6	0
DC5-1,2,3	40+	reference standard	1.0	0.13	0	1	0	0
PR-1,2,3	40+	reference standard	1.0	0.12	0	1	4	0
Reference Stand Summary								
Mean			**5**	**0.09**	**5**	**1**	**6**	**33.8**
Standard Error			3	0.01	4	0	1	7.5
Standard Deviation			16	0.05	23	0	4	45.7
Minimum			**1**	**0.04**	**0**	**1**	**0**	**0.0**
Maximum			**100**	**0.20**	**100**	**1**	**18**	**100.0**
Reference Standard Stand Summary								
Mean			**1.0**	**0.12**	**0**	**1**	**3**	**0**
Standard Error			0.0	0.00	0	0	1	0
Standard Deviation			0.0	0.01	0	0	3	0
Minimum			**1.0**	**0.11**	**0**	**1**	**0**	**0**
Maximum			**1.0**	**0.13**	**0**	**1**	**6**	**0**

Table D1. continued

		Variable Number ---->	13	14	15	16	17	18
		Variable Name ---->	***Vsoilperm***	***Vpore***	***Vsurfcon***	***Vclay***	***Vredox***	***Vtba***
		Metric ---->	soil permeability	% effective soil porosity	% stream reach with altered connections	% WAA with altered clay content	redoximorphic features present (1) absent (0)	tree basal area
		Units ---->	inches / hour					m2 / ha
Site-Plot Name	**Stand Age**	**Description**						
PC-PC	0	agricultural field, leveed	0.20	44	100	0	1	0.0
TW-PC	0	agricultural field, leveed	0.20	44	100	0	1	0.0
RR-PC1,PC2	0	agricultural field, ditched	0.20	44	0	0	1	0.0
Elkcrk1	0	ag field- proposed mitig/ditched	0.25	45	50	0	1	0.0
PRFW1-1,2,3	0	agricultural field, land levelled	0.20	44	0	0	1	0.0
PRFW2-1,2,3	0	agricultural field, land levelled	0.20	44	0	0	1	0.0
PRFW3-1,2,3	0	agricultural field, land levelled	0.20	44	0	0	1	0.0
Rold Ag 1-5	0	agricultural field-different soils	1.12	29	0	0	1	0.0
PRA-1,2	0-5	hammered, reclaim, compacted	0.00	26	80	0	0	0.0
ERMit1-1,2,3	2	mitigation site	0.13	44	0	0	1	0.0
NCMit1-1,2,3	5	BLH Mitigation -drier end of site	0.25	45	0	0	1	0.0
NCMit2-1,2,3	5	BLH Mitigation -wetter end of site	0.25	45	0	0	1	0.0
RC1-1,2,3	1-5	early successional, channelized	0.40	44	25	0	1	0.0
RC2-1,2,3	1-5	early successional, channelized	0.40	44	25	0	1	0.0
RC3-1,2,3	1-5	early successional, channelized	0.40	44	25	0	1	0.0
CCMit 1,2,3	5	mitigation site	1.30	44	0	0	1	0.0
ERMit2-1,2,3	10	mitigation site	0.13	47	0	0	1	18.8
OHCo 1,2	10	abandonded prior converted	0.13	47	0	0	1	15.0
Mudcr1-1,2	5-10	early succession-channelized &leveed	1.30	48	90	30	1	16.8
Rold1-1,2	unknown	BLH selective cut - 1998	1.30	43	0	0	1	24.5
Mudcr2-1,2,3	10-15	Selective cut- wetter due to road	1.30	46	50	0	1	13.7
Mudcr3-1,2,3	15-20	BLH -drier due to road	1.30	48	0	0	1	24.0
McCln1-1,2,3,4	20-25	selectively cut 10 ya	1	47	0	0	1	22
PoC1,2,3	20-25	mined watershed, channelized, sediment	0.13	44	0	0	1	17.7
IC-1,2,3	20-25	nuked, sediment, acid. beaver	0.13	44	33	0	1	9.3
EC1-1,2,3	20	channelized	0.40	43	0	0	1	11.1
EC2-1,2,3	20	channelized	0.40	43	0	0	1	11.8
EC3-1,2,3	20	channelized	0.40	43	0	0	1	8.7
Hanson1-1,2,3	25-30	selective cut	0.25	45	50	0	1	21.0
Rold2-1,2,3	25-30	selective cut	1.30	43	0	0	1	27.0
JC-1,2	30-40	channelized, high graded	0.13	47	25	0	1	11.5
DC2-1,2	30-40	wetter, open canopy	2.00	44	0	0	1	11.3
PR2-1,2	30-40	site scale standard, landscape altered	0.20	45	0	0	1	22.8
PR3-1,2,3,4,5,6	30-40	site scale standard, landscape altered	0.40	45	0	0	1	20.3
Mitproinc1-1,2 3	30-40	site scale standard, landscape altered	0.25	45	0	0	1	26.7
TC-1,2,3	30-40	channelized/ditched	1 30	44	100	0	1	28.0
WC-1,2,3	30-40	deep organic layer	0.40	43	0	0	1	24.0
CC1-3	40+	reference standard	0.20	45	0	0	1	18.5
CC2-1,2,3	40+	reference standard	0.20	45	0	0	1	23.0
CC3-1,2,3	40+	reference standard	1.30	45	0	0	1	25 3
DC1-1,2,3	40+	reference standard	2.00	44	0	0	1	17 7
DC3-1,2,3	40+	reference standard	0.60	43	0	0	1	21.9
DC4-1,2,3	40+	reference standard	0.60	43	0	0	1	26 0
DC5-1,2,3	40+	reference standard	0.20	45	0	0	1	19.6
PR-1,2,3	40+	reference standard	0.60	44	0	0	1	18.5
Reference Stand Summary								
Mean			**0.54**	**44**	20	**1**	**1**	**10**
Standard Error			0.09	1	5	1	0	2
Standard Deviation			0.52	4	33	5	0	10
Minimum			**0.00**	**26**	0	**0**	**0**	**0**
Maximum			**2.00**	**48**	100	**30**	**1**	**28**
Reference Standard Stand Summary								
Mean			**0.71**	**44**	**0**	**0**	**1**	**21.3**
Standard Error			0.22	0	0	0	0	1.1
Standard Deviation			0.64	1	0	0	0	3.2
Minimum			**0.20**	**43**	**0**	**0**	**1**	**17.7**
Maximum			**2.00**	**45**	**0**	**0**	**1**	**26.0**

Table D1 continued

			Variable Number ---->	19	20	21	22	23	24
			Variable Name ---->	*Vtden*	*Vsnag*	*Vwd*	*Vlog*	*Vssd*	*Vgvc*
			Metric ---->	tree density	snag density	volume of woody debris	volume of logs	shrub and sapling density	% cover ground vegetation
			Units ---->	stems / ha	stems / ha	m3 / ha	m3 / ha	stems / ha	
Site-Plot Name	**Stand Age**	**Description**							
PC-PC	0	agricultural field leveed		0	0	0.0	0.0	0	100
TW-PC	0	agricultural field. leveed		0	0	0.0	0.0	0	100
RR-PC1,PC2	0	agricultural field, ditched		0	0	0.0	0.0	0	100
Elkcrk1	0	ag field- proposed mitig/ditched		0	0	0.0	0.0	0	0
PRFW1-1,2,3	0	agricultural field, land levelled		0	0	0.0	0.0	0	100
PRFW2-1,2,3	0	agricultural field, land levelled		0	0	0.0	0.0	0	100
PRFW3-1,2,3	0	agricultural field, land levelled		0	0	0.0	0.0	0	100
Rold Ag 1-5	0	agricultural field-different soils		0	0	0.0	0.0	0	0
PRA-1,2	0-5	hammered, reclaim, compacted		0	0	0.0	0.0	0	48
ERMit1-1,2,3	2	mitigation site		0	0	0.0	0.0	67	30
NCMit1-1,2,3	5	BLH Mitigation -drier end of site		0	0	0.0	0.0	333	30
NCMit2-1,2,3	5	BLH Mitigation -wetter end of site		0	0	0.0	0.0	167	50
RC1-1,2,3	1-5	early successional, channelized		0	0	0.0	0.0	0	100
RC2-1,2,3	1-5	early successional, channelized		0	0	0.0	0.0	0	100
RC3-1,2,3	1-5	early successional, channelized		0	0	0.0	0.0	0	100
CCMit 1,2,3	5	mitigation site		0	0	0.0	0.0	14708	36
ERMit2-1,2,3	10	mitigation site		850	0	7.8	6.0	1800	38
OHCo 1,2	10	abandonded prior converted		750	0	8.9	0.0	13938	11
Mudcr1-1,2	5-10	early succession-channelized &leveed		738	25	15.5	4.7	2375	4
Rold1-1,2	unknown	BLH selective cut - 1998		250	25	69.5	53.0	313	22
Mudcr2-1,2,3	10-15	Selective cut- wetter due to road		533	42	55.0	40.7	3500	11
Mudcr3-1,2,3	15-20	BLH -drier due to road		917	8	19.5	3.0	708	5
McCln1-1,2,3,4	20-25	selectively cut 10 ya		350	31	15	8	2656	17
PoC1,2,3	20-25	mined watershed, channelized, sediment		483	0	39.3	36.0	2050	12
IC-1,2,3	20-25	nuked, sediment, acid, beaver		292	292	54.7	49.2	817	3
EC1-1,2,3	20	channelized		350	0	14.2	1.2	692	74
EC2-1,2,3	20	channelized		325	17	8.6	0.5	792	52
EC3-1,2,3	20	channelized		308	17	7.5	0.4	725	71
Hanson1-1,2,3	25-30	selective cut		517	25	32.0	23.0	2792	12
Rold2-1,2,3	25-30	selective cut		492	100	57.3	40.3	42	7
JC-1,2	30-40	channelized, high graded		288	13	80.0	74.5	3050	58
DC2-1,2	30-40	wetter, open canopy		375	0	8.7	3.5	3077	18
PR2-1,2	30-40	site scale standard, landscape altered		663	25	41.0	23.5	2563	12
PR3-1,2,3,4,5,6	30-40	site scale standard, landscape altered		508	38	58	45	2458	17
Mitproinc1-1,2,3	30-40	site scale standard, landscape altered		542	83	51.0	34.0	1042	37
TC-1,2,3	30-40	channelized/ditched		942	0	7.2	2.0	300	40
WC-1,2,3	30-40	deep organic layer		925	8	38.4	33.3	2483	0
CC1-3	40+	reference standard		508	58	22.5	20.0	700	19
CC2-1,2,3	40+	reference standard		550	43	40.0	20.0	346	2
CC3-1,2,3	40+	reference standard		708	50	45.0	36.8	898	10
DC1-1,2,3	40+	reference standard		525	40	38.0	32.6	980	11
DC3-1,2,3	40+	reference standard		592	45	22.3	18.3	2150	6
DC4-1,2,3	40+	reference standard		850	58	17.7	10.9	1465	19
DC5-1,2,3	40+	reference standard		567	33	30.5	25.2	577	18
PR-1,2,3	40+	reference standard		425	33	22.4	15.6	1260	4
Reference Stand Summary									
Mean				**308**	**20**	**19**	**13**	**1715**	**44**
Standard Error				53	8	4	3	537	6
Standard Deviation				322	51	24	20	3265	38
Minimum				**0**	**0**	**0**	**0**	**0**	**0**
Maximum				**942**	**292**	**80**	**75**	**14708**	**100**
Reference Standard Stand Summary									
Mean				**591**	**45**	**29.8**	**22.4**	**1047**	**11**
Standard Error				47	3	3.6	3.1	202	2
Standard Deviation				132	10	10.1	8.7	573	7
Minimum				**425**	**33**	**17.7**	**10.9**	**346**	**2**
Maximum				**850**	**58**	**45.0**	**36.8**	**2150**	**19**

Table D1 continued

Site-Plot Name	Stand Age	Description	25 Vohor % cover of O soil horizon	26 Vahor % cover of A soil horizon	27 Vcomp % concurrence with dominant plant species
PC-PC	0	agricultural field, leveed	0	100	0
TW-PC	0	agricultural field, leveed	0	100	0
RR-PC1,PC2	0	agricultural field, ditched	0	100	0
Elkcrk1	0	ag field- proposed mitig/ditched	0	50	0
PRFW1-1,2,3	0	agricultural field, land levelled	0	100	0
PRFW2-1,2,3	0	agricultural field, land levelled	0	100	0
PRFW3-1,2,3	0	agricultural field, land levelled	0	100	0
Rold Ag 1-5	0	agricultural field-different soils	0	100	0
PRA-1,2	0-5	hammered, reclaim, compacted	0	0	11
ERMit1-1,2,3	2	mitigation site	100	100	3
NCMit1-1,2,3	5	BLH Mitigation -drier end of site	0	100	23
NCMit2-1,2,3	5	BLH Mitigation -wetter end of site	0	100	39
RC1-1,2,3	1-5	early successional, channelized	0	100	0
RC2-1,2,3	1-5	early successional, channelized	0	100	0
RC3-1,2,3	1-5	early successional, channelized	0	100	0
CCMit 1,2,3	5	mitigation site	0	100	26
ERMit2-1,2,3	10	mitigation site	77	100	41
OHCo 1,2	10	abandonded prior converted	98	100	68
Mudcr1-1,2	5-10	early succession-channelized &leveed	100	100	68
Rold1-1,2	unknown	BLH selective cut - 1998	25	100	41
Mudcr2-1,2,3	10-15	Selective cut- wetter due to road	96	0	65
Mudcr3-1,2,3	15-20	BLH -drier due to road	95	100	72
McCln1-1,2,3,4	20-25	selectively cut 10 ya	94	100	64
PoC1,2,3	20-25	mined watershed, channelized, sediment	100	100	77
IC-1,2,3	20-25	nuked, sediment, acid, beaver	47	0	12
EC1-1,2,3	20	channelized	74	100	60
EC2-1,2,3	20	channelized	54	54	70
EC3-1,2,3	20	channelized	81	81	75
Hanson1-1 2,3	25-30	selective cut	100	100	81
Rold2-1,2,3	25-30	selective cut	98	100	43
JC-1,2	30-40	channelized, high graded	100	100	59
DC2-1,2	30-40	wetter, open canopy	86	100	100
PR2-1,2	30-40	site scale standard, landscape altered	60	100	61
PR3-1 2 3,4,5,6	30-40	site scale standard, landscape altered	64	100	85
Mitproinc1-1,2,3	30-40	site scale standard, landscape altered	56	100	73
TC-1,2,3	30-40	channelized/ditched	61	100	64
WC-1,2,3	30-40	deep organic layer	100	100	50
CC1-3	40+	reference standard	98	98	100
CC2-1,2,3	40+	reference standard	91	91	100
CC3-1,2,3	40+	reference standard	69	100	100
DC1-1,2,3	40+	reference standard	58	100	100
DC3-1,2,3	40+	reference standard	65	100	100
DC4-1,2,3	40+	reference standard	80	100	100
DC5-1,2,3	40+	reference standard	84	84	100
PR-1,2,3	40+	reference standard	96	1	100
Reference Stand Summary					
Mean			**48**	**89**	**39**
Standard Error			7	5	5
Standard Deviation			43	29	33
Minimum			**0**	**0**	**0**
Maximum			**100**	**100**	**100**
Reference Standard Stand Summary					
Mean			**80**	**96**	**100**
Standard Error			5	2	0
Standard Deviation			15	6	0
Minimum			**58**	**84**	**100**
Maximum			**98**	**100**	**100**

Units ---->

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
May 1999

3. REPORT TYPE AND DATES COVERED
Final report

4. TITLE AND SUBTITLE
A Regional Guidebook for Assessing the Functions of Low Gradient, Riverine Wetlands in Western Kentucky

5. FUNDING NUMBERS

6. AUTHOR(S)
William B. Ainslie, R. Daniel Smith, Bruce A. Pruitt, Thomas H. Roberts, Earl J. Sparks, Larry West, Gordon L. Godshalk, Michael V. Miller

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Wetlands Protection Section, U.S. Environmental Protection Agency, Region IV, 61 Forsyth Street, Atlanta, GA 30303-3104; U.S. Army Engineer Waterways Experiment Station, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199; Ecological Evaluation Section, U.S. Environmental Protection Agency, Region IV, 960 College Station Road, Athens, GA 30605; Tennessee Technological University, Department of Biology, P.O. Box 5063, Cookeville, TN 38050; U.S. Army Corps of Engineers, Louisville District, Newburgh Field Office, P. O. Box 489, Newburgh, IN 47629-0486; University of Georgia, Department of Crop and Soil Sciences, Athens, GA 30602; Alfred University, Environmental Studies Program, Alfred, NY 14802; Illinois State Geological Survey, 615 East Peabody Drive, Champaign, IL 61820

8. PERFORMING ORGANIZATION REPORT NUMBER
Technical Report WRP-DE-17

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Corps of Engineers
Washington, DC 20314-1000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
The Hydrogeomorphic (HGM) Approach is a collection of concepts and methods for developing functional indices and subsequently using them to assess the capacity of a wetland to perform functions relative to similar wetlands in a region. The approach was initially designed to be used in the context of the Clean Water Act Section 404 Regulatory Program permit review sequence to consider alternatives, minimize impacts, assess unavoidable project impacts, determine mitigation requirements, and monitor the success of mitigation projects. However, a variety of other potential applications for the approach have been identified including: determining minimal effects under the Food Security Act, designing mitigation projects, and managing wetlands.

This report uses the HGM Approach to develop a Regional Guidebook for assessing the functions of low gradient, riverine wetlands in western Kentucky. The report begins with a characterization of low gradient, riverine wetlands in the western Kentucky, then discusses (a) the rationale used to select functions, (b) the rationale used to select model variables and metrics, (c) the rational used to develop assessment models, and (d) the data from reference wetlands used to calibrate model variables and assessment models. Finally, it outlines an assessment protocol for using the model variables and functional indices to assess low gradient, riverine wetlands in western Kentucky.

14. SUBJECT TERMS
See reverse.

15. NUMBER OF PAGES
236

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED		

14. Subject Terms

404 Regulatory Program
Assessment
Classification
Clean Water Act
Ecosystem
Evaluation
Function
Functional Assessment
Functional Profile
Geomorphology
Hydrogeomorphic (HGM) Approach
Hydrology
Impact Analysis
Index
Indicators
Kentucky
Landscape
Method
Mitigation
Model
National Action Plan
Procedure
Reference Wetlands
Restoration
Value
Wetland